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Assessment of Bacteria and Virus Emissions at a Refuse Derived Fuel Plant and Other Waste Handling Facilities

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Assessment of Bacteria and Virus Emissions at a Refuse Derived Fuel Plant and Other Waste Handling Facilities

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This report presents the results of work carried out by Midwest Research Institute for the Environmental Protection Agency to determine relative levels of bacteria and virus in order to compare these levels at the St. Louis Refuse Processing Plant with those at four other types of waste handling facilities (i.e., an incinerator, a waste transfer station, a wastewater treatment plant, and a landfill). This work also included testing to determine bacterial removal efficiency of the Environmental Protection Agency mobile fabric filter (baghouse) operating on a slipstream drawoff of the exhaust duct from the air classifier at the St. Louis Refuse Processing Plant.

The results showed that airborne bacterial levels, both in-plant and at the property line, are generally higher for the refuse processing plant than for the other types of waste handling facilities that were tested. Fabric filter system applied to a primary source of dust emission (the air density separation exhaust) at the refuse processing plant can significantly reduce particulate and bacteria emissions.

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ASSESSMENT OF BACTERIA AND VIRUS EMISSIONS AT A REFUSE DERIVED FUEL PLANT AND OTHER WASTE HANDLING FACILITIES

by

D. E. Fiscus
P. G. Gorman
M. P. Schrag
L. J. Shannon
Environmental Systems Section
Midwest Research Institute
Kansas City, Missouri 64110

EPA Contract No. 68-02-1871

Project Officer

Carlton C. Wiles
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research, a most vital communications link between the researcher and the user community.

The St. Louis-Union Electric-Environmental Protection Agency refuse fuel project was the first demonstration of the use of solid waste as a supplementary fuel in power plant boilers for generating electricity. In addition to the demonstrations, research tasks were conducted to evaluate the relative levels of airborne bacteria and virus at the St. Louis Refuse Processing Plant. This report presents the results of these evaluations. It provides data on in-plant and property line concentrations as well as comparisons to concentrations at other waste handling facilities.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This report presents the results of work carried out by Midwest Research Institute for the Environmental Protection Agency to determine relative levels of bacteria in order to compare these levels at the St. Louis Refuse Processing Plant with those at four other types of waste handling facilities (i.e., an incinerator, a waste transfer station, a wastewater treatment plant, and a landfill). This work also included testing to determine bacterial removal efficiency of the Environmental Protection Agency mobile fabric filter (baghouse) operating on a slipstream drawoff of the exhaust duct from the air classifier at the St. Louis Refuse Processing Plant.

The results showed that airborne bacterial levels, both in plant and at the property line, are generally higher for the refuse processing plant than for the other types of waste handling facilities that were tested. A fabric filter system applied to a primary source of dust emission (the air density separation exhaust) at the refuse derived fuel plant can significantly reduce particulate and bacteria emissions.

This report was submitted in fulfillment of Contract No. 68-02-1871 by Midwest Research Institute under the sponsorship of the U.S. Environmental Protection Agency.

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This report was prepared for the Environmental Protection Agency under Contract No. 68-02-1871. It describes an investigation of bacteria and virus emissions conducted by Midwest Research Institute at the St. Louis Refuse Processing Plant, and at four other waste handling facilities during the period November 1 to December 1, 1976, and discusses related information based on a search of the technical literature. The report also includes results of analysis for trace metal and asbestos emissions from the air classifier system at the St. Louis Refuse Processing Plant and an evaluation of a pilot scale baghouse for control of particulates and bacteria and virus emissions from the air classifier system.

Mr. Doug Fiscus, Mr. Paul Gorman, Mr. M. P. Schrag, and Dr. L. J. Shannon were the principal authors of this report, with assistance from Dr. Frank Wells, Dr. William Spangler, Mr. M. Fletcher, Mr. Girish Desai, Mr. R. White, Mr. Stan Reigel, Mr. Bruce DaRos, and Mr. P. Reider.

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Approved for:

MIDWEST RESEARCH INSTITUTE

L. J. Shannon

L. J. Shannon, Director
Environmental and Materials Sciences
  Division

February 21, 1978

SECTION 1

SUMMARY

Tests were carried out in November and early December of 1976 to determine relative bacteria and virus levels at the property lines and at in-plant locations for the St. Louis Refuse Processing Plant* and a number of other related waste handling facilities. The primary purposes of the tests were to:

a. Provide data for comparison of airborne bacterial and viral levels at the refuse processing plant with those other facilities.

b. Determine any correlation between bacteria concentration and particulate particle size.

c. Obtain data for comparison of airborne trace element and asbestos concentrations at each facility.

d. Evaluate fabric filter collection efficiency for bacteria.

The facilities tested were:

- A municipal incinerator;
- The St. Louis Refuse Processing Plant;
- A wastewater treatment plant;
- A refuse transfer station; and
- A sanitary landfill.

In addition to the above facilities, testing was also carried out in downtown St. Louis. Bacterial levels were also ascertained for a refuse collection packer truck.

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* The St. Louis Refuse Processing Plant was a 272 Mg/day test facility that operated from 1972 to 1976. The plant produced refuse derived fuel (RDF) for use by the Union Electric Company.

The test activity was supplemented by a comprehensive search of the technical literature to define the current state of knowledge on bacteria and virus emissions from waste handling facilities.

Three days of testing were carried out at each of the above facilities with Hi-Vol ambient air filters and Andersen agar plate impactors at the property lines (one upwind and three downwind) and at three in-plant locations. In addition, supplemental tests were conducted at the RDF plant to evaluate emissions of particulate trace metals, asbestos, and microorganisms from the air classifier system, and removal efficiency of particulates and microorganisms by a pilot scale mobile filter unit (baghouse) provided by the Environmental Protection Agency (EPA).

Each of the Andersen impactor stages (agar plates) was examined to determine total bacteria colony counts. The Hi-Vol filters were assayed for the following:

Bacteria

Total aerobic bacteria
Salmonella
Staphylococcus aureus
Total coliform
Fecal coliform
Fecal Streptococci
Klebsiella sp.

Virus (by one cell line)

Adenoviruses
Enteroviruses

Test methodologies and analysis procedures are described in the report.

BACTERIA AND VIRUS EMISSIONS

Bacteria and virus assays of the property line and in-plant Hi-Vol filters, plus the total bacteria colony counts from the Andersen impactors, were the focal point of this program. The primary purpose in obtaining these data was to make a comparison of the data for the processing plant with that of the other four facilities. The Hi-Vol filter sampling methodology was utilized because it provides long-term high flow rate sampling capability. However, bacteria/virus concentrations must not be considered as absolute values because this type of sampling method probably produces considerable die-off of bacteria and viruses. Realizing this, the data best serve only the intended purpose, a comparison of facilities.

It was intended that comparisons be made for both bacteria and virus. However, all virus assays were negative so no virus comparisons are possible. We could not ascertain that sampling methods did not adversely affect viruses that might have been present or that levels were below detection limits. Therefore, it is not possible to draw any definite conclusions regarding relative virus levels.

A comparison of bacteria levels at each of the plants was carried out, using both the Hi-Vol sample results and the Andersen impactor results for four of the seven species tested. No results are presented for Salmonella sp., Staphylococcus aureus, and Klebsiella sp. because almost all were negative and from this it is inferred that their number or viability is low. Results for the other four species, based on the Hi-Vol samples, showed in general, that the range of airborne bacterial levels was highest downwind of the RDF plant. Detected levels at all of the plants covered a rather broad range in most cases. We do not know the reason for these large differences but it does make interpretations and intercomparisons very difficult. Also, it is not possible to be certain that downwind and in-plant samples at the RDF plant were not influenced by the nearby incinerator operations. There was also the unfortunate circumstance that upwind bacterial levels were highest during the tests at the RDF plant. Numerically, the higher upwind levels could not account for the higher downwind values but interpretation of the results is more complicated.

The ambient Hi-Vol results did show the highest downwind levels at the processing plant, for all four species of bacteria. A rank ordering of the facilities given in Table 1 showed lowest downwind levels at the landfill or wastewater treatment plant depending on species of bacteria.

In-plant Hi-Vol results shown in Table 2 yielded roughly the same relative ranking of facilities as did the ambient results.

The in-plant sites included the packer truck which had bacterial levels comparable with the highest of the other locations that were actually located within the plants. In-plant levels at the RDF plant are lower than the levels measured during packer truck sampling.

Andersen agar plate impactor samples taken at the same upwind/downwind and in-plant locations showed the same general trend in total bacteria colony counts as did the Hi-Vol results. That is, the downwind levels were highest at the RDF plant and lowest at the landfill, while the in-plant levels were about equally high at the RDF plant, incinerator, and waste transfer station.

One of the interesting findings of the in-plant Andersen tests was that by far the highest level of total bacteria colony counts occurred in the pressroom basement of the wastewater treatment plant. These Andersen samples were

TABLE 1. RANKING OF PLANTS BASED ON AVERAGE AMBIENT BACTERIAL LEVELS FROM HI-VOL SAMPLES[a]

	Total bacteria count	Total coliform	Fecal coliform	Fecal Streptococci
Upwind[b]	RDF plant	RDF plant	RDF plant	RDF plant
	Incinerator	Downtown	Downtown	Incinerator
	Downtown	Incinerator	Waste transfer	Waste transfer
	Waste transfer	WWTP	Incinerator	Downtown
	WWTP	Waste transfer	WWTP	WWTP
	Landfill	Landfill	Landfill	Landfill
Downwind[b]	RDF plant	RDF plant	RDF plant	RDF plant
	Incinerator	Waste transfer	Waste transfer	Incinerator
	Downtown	Incinerator	Incinerator	Waste transfer
	WWTP	Landfill	WWTP	Downtown
	Waste transfer	Downtown	Downtown	WWTP
	Landfill	WWTP	Landfill	Landfill

[a] Statistical comparisons of bacterial levels are included later in this report.

[b] Downtown location has been included in both groups (upwind and downwind) for comparison purposes.

TABLE 2. RANKING OF PLANTS BASED ON AVERAGE IN-PLANT BACTERIAL LEVELS FROM HI-VOL SAMPLES

Total bacteria count	Total coliform	Fecal coliform	Fecal Streptococci
RDF plant	Packer truck	Packer truck	Waste transfer
Packer truck	RDF plant	RDF plant	Packer truck
Incinerator	Waste transfer	Waste transfer	RDF plant
Waste transfer	Incinerator	Incinerator	Incinerator
WWTP	Landfill	Landfill	Landfill
Landfill	WWTP	WWTP	WWTP

specifically taken at this location during the time when the operators were dumping the solid residue (filter cake) from the filter presses.

Results of the Andersen impactor tests were not directly comparable with the Hi-Vol results because of the differences in sampling times and sampling rates, the expected die-off of bacteria on the Hi-Vol filters, and the fact that Andersen results were only colony counts. In fact, the major reason for doing the impactor tests was to obtain information on the number of bacteria containing particles as a function of particle size. The results for the air sampled at most locations did not show a decrease in the number of bacteria containing particles with decreasing particle size. Although it is reasonable to assume that the mass of particulate matter per unit volume of air would decrease with decreasing size, these data indicate that the number of bacteria containing particles did not decrease with decreasing size.

A statistical analysis of the Hi-Vol and Andersen bacteria data was carried out and confirmed the results discussed above.

In an effort to obtain additional information that would aid in assessing the significance of the bacteria and virus results, a comprehensive search of the literature was carried out as part of this program. This search revealed that concentrations of bacteria colonies in air may range from 200/m^3 in a laboratory up to 700,000/m^3 in a sewage treatment plant, while more common locations (offices, factories, and streets) may range from 2,000 to 4,000/m^3. However, nothing in the literature search provided a basis for judging whether these or any other levels are, or are not, hazardous. The single conclusion that can be drawn is: if the relative levels measured at the RDF plant are significantly higher than at other related facilities, then this is probably not desirable, and efforts should be made to reduce airborne bacterial levels. Controls could include use of control devices on emission sources (e.g., fabric filters) or process modifications.

TRACE ELEMENT EMISSIONS

Trace element concentrations were determined for the discharge of the air classifier system and for the upwind/downwind Hi-Vol samples. Lead (Pb) and Zinc (Zn) were the trace elements having the highest concentration in the particulate emitted from the air classifier system. However, all trace elements measured in this stream were below their respective threshold limit values (TLVs).

Trace element analyses of the property line Hi-Vol samples showed that there was an increase in the concentration of certain elements between the upwind/downwind samples at some of the facilities. In an effort to assess the significance of these concentrations, they were compared with 1/100 of the respective TLVs,* and it was found that all were below this value, except for Pb. Downwind Pb concentrations exceeded 1/100 of TLV at the incinerator and RDF plant and were just equal to 1/100 of TLV at the waste transfer station. It appeared that handling of refuse at these plants, or some other plant activity, may have contributed significantly to the burden of Pb in downwind ambient air. Indications of Pb in air might have been due to the vehicular traffic in such plants (e.g., refuse collection trucks) but this seemed to be negated by the samples taken at the downtown location which showed Pb concentrations about the same as upwind values at the plants, even though the downtown location had high vehicular traffic nearby.

PARTICULATE EMISSIONS AND FABRIC FILTER PERFORMANCE

Results of the particulate tests on the air classifier system at the RDF plant showed uncontrolled particulate emissions of 14.2 to 17.8 kg/hr (0.26 to 0.36 g/dNm^3). The pilot scale mobile filter, taking a sidestream drawoff (0.05 dNm^3/sec) from the air classifier discharge, achieved an overall mass efficiency of 99.95% for removal of that particulate. Samples of the particulate discharged from the air classifier system were analyzed for bacteria and were found to contain average total bacteria of 5.3×10^7 counts/g, which was about the same as that found in the shredded raw refuse. Bacteria samples taken by impingers at the inlet and outlet of the mobile filter indicated a removal efficiency of 99.6% for total bacteria and at least 99.9% for specific types of bacteria (e.g., total coliform). This result confirmed the expectation that a filter system on the air classifier discharge should be able to provide high removal efficiency for particulate and associated bacteria.

Particulate matter collected at the discharge of the air classifier system was also analyzed for asbestos. Results of the asbestos analysis indicated that asbestos fibers were present, composing as much as 1.6% of the emitted particulate. However, the data revealed that the number concentration of emitted asbestos was only 0.10 fiber/cc of air. This concentration, in the air classifier discharge itself, was considerably below the TLV for asbestos (5 fibers/cc).

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* TLVs refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. (11) The TLVs used refer to time-weighted concentrations for an 8-hr workday and 40-hr workweek.

SECTION 2

INTRODUCTION

Under contract to EPA, Midwest Research Institute (MRI) has been involved in an EPA supported program for testing and evaluating of the EPA-City of St. Louis-Union Electric Company RDF demonstration project since December of 1973. These equipment and environmental evaluations have covered both the refuse processing plant (1) and the Meramec Power Plant. (2)

Most of the environmental evaluations at both facilities were directed to particulates, gases, and trace metals. The tests on particulate emissions from the air classifier system at the RDF plant also included an initial analysis for bacteria and virus. Since these particulates consist basically of municipal solid waste (MSW), it was not surprising that findings showed the presence of bacteria and virus in the emissions. However, these findings did warrant further testing to determine bacteria and virus levels at the property line of the RDF plant, at certain in-plant locations, as well as similar testing at other types of waste handling facilities.

The plan that was developed for carrying out such testing was intended to be more expansive and complex than the initial bacteria and virus tests. Development of this plan included submission of the preliminary plan to a number of experts in the field for their comments and suggestions. These were incorporated into the final plan wherever possible. Some reviewers did comment on the shortness of the tests (3 days at each plant) but the testing could not be expanded because time and funds were limited, and it was felt that the plan would still allow intercomparisons to be made.

The data acquired allowed intercomparison of levels and provided a means of evaluating relative significance of refuse processing operations. The work included an extensive search of the literature in an effort to compile all available information that might be useful in evaluating the test data for these waste handling facilities.

Actual field testing took place in November and early December 1976, with 3 days of testing at each of five waste handling facilities as follows:

* A municipal refuse incinerator;

* The St. Louis Refuse Processing Plant;

* A sewage treatment plant;

* A refuse transfer station; and

* A sanitary landfill.

In addition to the above plants, testing was also carried out in downtown St. Louis. Bacterial levels were also ascertained for a refuse collection packer truck.

The test plan for the sampling and a description of the actual sampling and analysis methodology are presented in the next sections of this report. These descriptions are followed by the presentation and discussion of test results, and an interpretation of those results incorporating information compiled in a search of the literature in the areas of airborne bacteria and virus.

SECTION 3

TEST PLAN

The sampling and analysis plan (test plan) was developed through the joint efforts of EPA and MRI. The sampling and analysis plan was based on review of the available existing information, previous results and discussions relative to the preliminary work done at St. Louis, and what could be conducted within the framework of available time and funding. A draft of the sampling and analysis plan was sent to certain knowledgeable people for their review so that suggested revisions could be incorporated into the final test plan. Specific details of the entire test plan are given in Appendix A. The appendices also include a description of the field test methodology (Appendix B) and the laboratory analysis methodology (Appendix C). MRI will also be preparing a separate report in the near future to explain in more detail the sampling and analysis methodologies used in this program and to make additional recommendations for future work needed in these areas.

The sampling equipment used during the three test days at each plant were Hi-Vol ambient air samplers, which provide high sampling rates of approximately 19 liters/sec (40 cfm) for relatively long periods of time (6 hr).* These were supplemented by Andersen agar plate impactors with backup impingers, to obtain information on the size distribution of the bacteria containing particles and determine if any viruses penetrated the impactor into the impinger.

The locations of the equipment at the test sites were as follows: (a) Hi-Vol samplers, one upwind and three downwind; (b) Hi-Vol with precyclone samplers, three in-plant; and (c) Andersen impactors, one upwind, one downwind, and three in-plant. All upwind and downwind locations were at the property lines.

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* Sampling time of 6 hr was arbitrarily selected. There were no existing data available to determine sampling time for optimizing bacteria counts (i.e., bacteria counts as a function of sampling time). Also, no background sampling was performed since upwind samples were being taken each day. Other sampling techniques were also considered (AGI impingers) but not selected because of various disadvantages (e.g., low sampling rates).

The placements of the downwind Hi-Vol samplers were a primary location directly in line with the wind direction from the plant and two secondary locations, one on each side of the primary to include approximately a 30 degree angle from the upwind location. This placement allowed for normal slight variations in wind direction. The wind direction was constantly monitored by a strip chart recorder which was checked hourly by the test crew. When a major change in wind direction occurred, the Hi-Vols were moved to be in line with the wind. The Andersen impactor samples were taken at the same locations as the upwind and primary downwind Hi-Vols.

The locations of the in-plant Hi-Vols were selected for each test site to sample the areas where the bacterial and viral counts were suspected to be at the highest levels. The Andersen impactors were operated at the same in-plant locations as the Hi-Vols. One 30-sec Andersen sample was taken at each of the three in-plant locations on each test day.

The sample period for the Hi-Vols was approximately 6 hr at all locations. The sample period for the Andersen impactors was 10 min for the upwind and downwind locations and 30 sec for the in-plant locations. The sampling times for the in-plant and property line Andersens were different because of the suspected higher concentrations of in-plant bacteria and because it is undesirable to overload the agar plates in the Andersen sampler.

During the sampling periods for the incinerator and the RDF plant, additional Hi-Vol samples were taken in downtown St. Louis, Missouri. These samples were taken as representative of an urban location. Additionally, two Hi-Vol samplers were attached to the back of a 15 m^3 (20 yd^3) packer truck and were operated on 3 days when the crew was picking up MSW on three different collection routes.

Tests to define the performance of a mobile fabric filter on the air classifier exhaust stream were also conducted during the sampling activity at the RDF plant. These tests involved:

* A Hi-Vol sampler in the air classifier exhaust duct.

* Impinger samplers at the inlet and outlet of a mobile filter on a sidestream taken from the air classifier exhaust duct.

* Refuse grab samples taken on the product discharged from the hammermill.

Selection of the bacterial and viral analyses that were to be performed on the property line and in-plant Hi-Vol samples was an important part of the test plan development. Ultimately, it was decided that each sample would be analyzed for the bacteria and virus types shown according to the Level 1 analysis listed in Table 3 and that some selected samples would be further subjected to Level 2 analysis in order to generate data which are of epidemiological interest to this program and which may be used as reference values for any future tests.

TABLE 3. ANALYSIS SPECTRUM FOR BACTERIA AND VIRUS

Level 1 tests[a]	Level 2 tests[a]
Bacteria	
Total aerobic plate count	Relative changes in predominant morphological groups
Salmonellae	(1) Determine serotypes (2) Antibiotic sensitivity
Staphylococcus aureus (direct plate count)	(1) Coagulase production (2) Antibiotic sensitivity) (3) Bacteriophage typing
Total coliform (MPN)	No additional assays
Fecal coliform (MPN)	Enteropathogenic serotype of *E. coli*
Fecal Streptococci (direct plate count)	No additional assays
Klebsiella sp. (est. from selective media)	Serotype for pathologically significant groups
Virus	
Estimations of population sizes of adenoviruses and enteroviruses. To be done using two cell lines and determining pfu/m^3	Serological identification of the relative populations of adenoviruses (human type), polioviruses (vaccine and wild types), coxsakie viruses (A and B), and echoviruses.

[a] Level 2 tests for bacteria and virus include all analysis shown in Level 1 column plus additional analysis shown in the Level 2 column.

In addition to the bacterial and viral analyses listed above, other analyses were performed on some samples. Specifically, a part of the upwind and primary downwind Hi-Vol samples taken during a single day at each of the plants was analyzed to determine trace metals and microbial morphology. Similarly, the Andersen impactor samples taken at the same two locations during one test day were analyzed to determine microbial morphology on each stage, and virus (Level 1) in the backup impinger.

SECTION 4

RESULTS AND DISCUSSION

The bacteria and virus sampling activities were the major components of this test program and the results of these activities are presented in this section. Supplementary information on particle morphology, trace element emissions, and the performance of the mobile fabric filter is discussed after the bacteria and virus presentation.

BACTERIA AND VIRUS EMISSIONS

Previous testing conducted at the St. Louis Processing Plant in 1975 (1) included some bacteria and virus assays on particulate emission sources, primarily the air classifier discharge. In the air classifier discharge, it was found that the emitted particulate contained bacteria concentrations of about the same order as raw refuse, as might be expected. Evaluation of these results indicated that the bacteria and virus emissions might be of concern, but the 1975 tests did not include any samples taken at in-plant or property line locations. As discussed previously, the test plan for this program was designed to obtain data at both in-plant and property line locations. Results of tests of bacteria and virus emissions are presented in separate subsections.

Bacteria Emissions

The discussion of bacteria emissions is arranged in three subsections:

1. Refuse samples;

2. Air classifier discharge samples and mobile filter samples; and

3. Hi-Vol and Andersen samples at property lines and in-plant.

Refuse Samples--

Results of the bacteria analysis on the shredded refuse from the hammermill are given in Table 4. These data show an average of 4×10^7 total bacteria counts per gram, which is in reasonable agreement with values reported

TABLE 4. SHREDDED REFUSE SAMPLES - BACTERIA RESULTS
(Counts per gram of material)

Sample	Date	Total Bacteria count	Total coliform	Fecal coliform	Fecal Streptococci
RS-1	11/8/76	6.9×10^7	$> 2.40 \times 10^5$	$> 2.40 \times 10^5$	2.7×10^5
RS-2	11/8/76	3.3×10^7	$> 2.40 \times 10^5$	$> 2.40 \times 10^5$	1.8×10^5
RS-3	11/8/76	4.2×10^7	$> 2.40 \times 10^5$	$> 2.40 \times 10^5$	0.57×10^5
RS-4	11/9/76	3.9×10^7	$> 2.40 \times 10^5$	0.92×10^5	2.0×10^5
RS-5	11/9/76	1.7×10^7	$> 2.40 \times 10^5$	0.24×10^5	0.60×10^5
RS-6	11/9/76	2.2×10^7	$> 2.40 \times 10^5$	0.92×10^5	0.67×10^5
RS-7	11/10/76	2.0×10^7	$> 2.40 \times 10^5$	0.079×10^5	0.67×10^5
RS-8	11/10/76	7.5×10^6	$> 2.40 \times 10^5$	0.92×10^5	4.3×10^5
RS-10	11/11/76	8.4×10^7	$> 2.40 \times 10^5$	$> 2.4 \times 10^5$	1.9×10^5
RS-11	11/11/76	6.0×10^7	$> 2.40 \times 10^5$	$> 2.4 \times 10^5$	2.8×10^5
RS-12	11/11/76	4.8×10^7	$> 2.40 \times 10^5$	0.92×10^5	0.53×10^5
Average		4.6×10^7	$> 2.4 \times 10^5$	1.45×10^5	1.68×10^5

by Peterson. (3) The fecal coliform counts of 240,000/g arc in similar agreement. No comparison data were available for fecal Streptococci but the range of the values (5.3×10^4 to 4.3×10^5) seems high in relation to total coliform and fecal coliform. The analyses did not indicate the presence of Salmonella, *Staphylococcus aureus*, or Klebsiella in any of the 11 refuse samples.

Air Classifier Discharge and Mobile Filter Samples--

Test data for bacteria in the particulate emitted from the air classifier system are given in Table 5, with all species having about the same concentrations as in the shredded refuse. These data verify previous results and indicate that the discharged particulate is similar to the shredded refuse itself in terms of bacterial levels.

Data for the impinger sampling done at the inlet and outlet of the EPA mobile filter (see Appendix E) are included in Table 5. Bacteria data were obtained for only one of the three test days but the results do show a significant decrease in bacteria levels across the mobile filter, indicating a removal efficiency of 99.6% for total bacteria and at least 99.9% for total coliform, fecal coliform, and fecal Streptococci.

The data in Table 5 have an interesting aspect in that they provide a means of comparing bacteria values determined by two methods. That is, one can compare the results of the Hi-Vol stack sampler used in the air classifier discharge with the impinger sampler used at the inlet of the mobile filter. These samplers were essentially sampling the same stream but the impinger sampler was operated for approximately 6 hr while the air classifier Hi-Vol was operated for only about 1/2 hr. Conversion of the data for the air classifier discharge, for November 11, 1976, to counts per cubic meter, shows the following:

	Concentrations in counts/m^3			
	Total bacteria	Total coliform	Fecal coliform	Fecal Streptotocci
Impinger - mobile filter inlet	5.25×10^8	3.36×10^6	4.62×10^5	2.25×10^6
Hi-Vol - air classifier discharge	0.12×10^8	$> 0.07 \times 10^6$	0.28×10^5	0.22×10^6

Although there was only one mobile filter inlet sample, the above comparison may be indicative of increased die-off, on the order of 90 to 97%, for the Hi-Vol filter samples (air classifier discharge) as opposed to impinger samples (mobile filter inlet). This would not be unexpected but is important

TABLE 5. BACTERIA RESULTS FOR AIR CLASSIFIER DISCHARGE AND MOBILE FILTER SAMPLES

Sample	Date	Total bacteria count	Total coliform	Fecal coliform	Fecal Streptococci
Air classifier discharge - (counts per gram of particulate)					
Air classifier 1	11/9/76	6.2×10^7	> 240,000	> 240,000	6.7×10^5
Air classifier 2	11/10/76	5.9×10^7	> 240,000	92,000	8.0×10^5
Air classifier 3	11/11/76	3.9×10^7	> 240,000	92,000	7.3×10^5
Average		5.3×10^7 (1.6×10^7)[a]	> 240,000 (> 72,000)[a]	> 140,000 (> 42,000)[a]	7.3×10^5 (2.2×10^5)[a]
Mobile filter (counts/m^3 of air)					
Mobile filter inlet	11/11/76	$5.25 \times 10^8/m^3$	$3.36 \times 10^6/m^3$	$4.62 \times 10^5/m^3$	$2.25 \times 10^6/m^3$
Mobile filter outlet	11/11/76	$2.1 \times 10^6/m^3$	$3.57 \times 10^2/m^3$	$2.3 \times 10^2/m^3$	$2.1 \times 10^3/m^3$

[a] Values in parentheses are counts/m^3 of air, based on counts per gram and average particulate concentrations of 0.30 g/m^3.

in regard to the values indicated for the in-plant and property line samples obtained with Hi-Vol filters.

Hi-Vol and Andersen Samples at Property Lines and In-Plant--

Sampling at property lines and in-plant locations was performed using Hi-Vol and Andersen samplers. The results from each system are presented separately in the following subsections.

Hi-Vol test results (property lines and in-plant)--Hi-Vol filter samplers (≈ 1 m^3/min) were operated for 6 hr during three (or more) test days at each plant in the locations listed below:

RDF plant	Incinerator	Waste transfer station	Wastewater treatment plant	Sanitary landfill
Upwind (1)	Upwind (1)	Upwind (1)	Upwind (1)	Upwind (1)
Downwind (3)	Downwind (3)	Downwind (3)	Downwind (3)	Downwind (3)
Control room	Scale room	Truck ramp	Pri. settling basin	Scale
Packer station	Crane	Tipping floor	Aeration basin	Working face
Tipping floor	Tipping floor	Tipping floor	Pressroom	Working face
	Packer truck (2)		Pressroom basement	
Downtown	Downtown			

Results for all of the Hi-Vol samples are shown in Table 6. This table does not include three of the bacteria types because all results were negative for Salmonella and Staphylococcus, and Klebsiella was detected in only four samples at levels just above the sensitivity of the analysis methods (i.e., 1 count/g of filter, or approximately 0.008 counts/m^3 of air sampled).* Companion data for the results given in Table 6 (e.g., sampling rates and meteorological conditions) are tabulated in Appendix G. Most of the meteorological conditions during testing were good, with dry bulb temperatures between -4 and 22°C, moderate to low wind speeds, and relative humidity between 40 and 60%.

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* It was noted in Table 6 that fecal Streptococci counts were relatively high compared to fecal or total coliform counts. The reason for this is not known but may reflect selective survival of different bacterial types in the Hi-Vol sampling method. However, a similar finding was made in work by personnel at the University of California (Berkeley) in the Richmond Field Station Resource Recovery System. (12)

TABLE 6. HI-VOL DATA

		INCINERATOR - BACTERIA COUNT/CUBIC METER (Count/m^3) MPN[a]															
		Total plate count				Total coliform				Fecal coliform				Fecal Streptococci			
	Test date Test day	11-1 0	11-2 1	11-3 2	11-4 3	11-1 0	11-2 1	11-3 2	11-4 3	11-1 0	11-2 1	11-3 2	11-4 3	11-1 0	11-2 1	11-3 2	11-4 3
Upwind		<1,510	470	6,045	1,950	<0.061	0.019	0.191	0.225	<0.061	0.019	0.020	<0.020	5.75	0.940	7.64	<0.975
Dw - West or North			1,900	5,420	2,740		1.18	5.16	1.19		<0.020	0.316	0.120		<0.952	5.73	3.67
Dw - prim			2,910	3,820	2,958		0.768	1.51	1.62		0.224	<0.020	0.093		1.95	2.87	1.87
Dw - East or South			1,960	8,610	12,400		0.225	4.68	0.038		0.049	0.134	<0.020		1.96	1.91	1.91
Scale room		34,800	47,000	47,800	Mold	1.64	0.416	0.163	<0.017	0.676	0.416	0.020	<0.017	261	166	3.82	1.48
Crane		59,700	1.09 x 10^5	66,950	1.115 x 10^5	4.88	3.30	2.11	0.295	1.60	3.30	0.316	<0.018	<2.13	363	100	72.3
Tipping floor		59,900	2.39 x 10^5	41,100	15,300	18.6	1.18	0.468	0.204	4.86	1.18	0.468	<0.018	261	230	411	66.7
Downtown			<497	<497	1,820		0.486	0.655	0.199		0.328	<0.020	0.039		1.99	<0.992	0.907
Packing truck Left			1.06 x 10^5	1.14 x 10^5	81,000		> 352	251	> 324		>352	14.7	4.72		420	470	486
Right			1.09 x 10^5	Spread	13,500		> 352	3.76	> 324		>352	1.24	3.24		792	235	446

(continued)

TABLE 6 (continued)

	PROCESSING PLANT - BACTERIA COUNT/CUBIC METER (COUNT/m^3) MPN[a]																
		Total plate count				Total coliform				Fecal coliform				Fecal Streptococci			
	Test date Test day	11-8 0	11-9 1	11-10 2	11-11 3	11-8 0	11-9 1	11-10 2	11-11 3	11-8 0	11-9 1	11-10 2	11-11 3	11-8 0	11-9 1	11-10 2	11-11 3
Upwind		2,900	11,900	14,400	2,830	1.06	2.33	0.761	0.312	<0.020	0.767	0.068	<0.020	2.90	38.9	12.5	5.68
Dw - North or West		8,480	9,040	8,130	14,700	6.59	33.9	17.2	51.2	0.462	4.45	8.98	12.3	24.5	57.1	20.0	44.6
Dw - prim		3,790	40,700	30,600	7,600	3.32	>233	334	2.28	0.066	33.9	153	0.209	22.8	378	590	32.2
Dw - South or East		3,780	78,800	26,700	949	0.463	3.45	15.3	0.104	<0.020	0.079	3.34	<0.020	7.55	31.5	19.1	0.949
Control room		1.63 x 10^6	29,100	28,000	20,500	48.8	5.16	3.34	10.5	3.16	3.34	2.30	4.39	135	40.2	18.2	43.9
Packer station		2.67 x 10^5	24,800	3,820	10,800	>213	12.4	0.755	3.34	21.3	1.63	0.755	2.30	478	31.6	10.5	39.1
Tipping floor		2.60 x 10^5	90,600	93,000	50,300	>208	86.8	88.0	15.2	30.4	10.4	5.16	1.52	417	270	229	287
Downtown		1,300	712	< 956	<4,780	0.590	0.380	0.029	0.048	<0.025	<0.019	<0.029	<0.02	1.20	0.95	0.956	<0.956

(continued)

TABLE 6 (continued)

	WASTE TRANSFER STATION - BACTERIA COUNT/CUBIC METER (Count/m^3) MPN[a]																
		Total plate count				Total coliform				Fecal coliform				Fecal Streptococci			
	Test date Test day	11-22 1	11-23 2	11-24 3		11-22 1	11-23 2	11-24 3		11-22 1	11-23 2	11-24 3		11-22 1	11-23 2	11-24 3	
Upwind		< 477	< 491	2,910		0.020	<0.020	0.224		<0.020	<0.020	0.048		<0.953	< 0.983	4.86	
Dw - West or North		< 469	3,820	< 952		0.131	22.9	0.020		<0.018	3.34	< 0.020		<0.953	3.82	<0.952	
Dw - prim		1,430	478	<469		0.220	0.325	2.26		<0.020	<0.020	0.311		<0.956	<0.956	5.64	
Dw - East or South		< 478	< 477	714		1.63	0.163	0.315		<0.020	< 0.163	< 0.029		<0.956	<0.953	1.43	
Truck ramp		22,900	30,550	6,340		2.29	3.34	2.07		0.458	2.30	0.143		107	59.8	6,340	
Tipping floor - E.		30,550	7,830	2,870		153	2.26	3.34		8.98	1.22	0.439		203	26.3	14.3	
Tipping floor - N.		26,800	14,040	20,000		3.34	15.9	22.9		2.30	10.3	0.702		126	31.9	44.5	

(continued)

TABLE 6 (continued)

	WASTEWATER TREATMENT PLANT - BACTERIA COUNT/CUBIC METER (Count/m^3) MPN[a/]																
		Total plate count				Total coliform				Fecal coliform				Fecal Streptococci			
	Test date Test day	11-15 1	11-16 2	11-17 3	11-18 4	11-15 1	11-16 2	11-17 3	11-18 4	11-15 1	11-16 2	11-17 3	11-18 4	11-15 1	11-16 2	11-17 3	11-18 4
Upwind		2,700	517	<477	<492	0.447	0.021	<0.020	<0.020	0.027	<0.021	<0.020	<0.020	<1.35	<1.04	<0.957	<0.985
Dw - West or North		<1,590	478	5,720	<478	0.350	0.048	0.048	<0.020	<0.031	<0.020	<0.020	<0.020	1.59	<0.956	<0.953	<0.956
Dw - Prim		3,980	<477	477	492	1.05	<0.020	<0.020	0.039	<0.026	<0.020	<0.020	0.020	<1.33	<0.953	<0.953	<0.985
Dw - East or South		1,560	<952	478	<478	0.170	<0.020	<0.020	0.020	<0.031	<0.020	<0.020	<0.020	<1.56	<0.952	<0.956	<0.956
Prim set. B.		<833	<477	<478	1.74 × 10^5	0.134	<0.020	0.029	0.020	<0.034	<0.020	<0.020	<0.020	<1.66	<0.956	<0.956	<0.956
Aeration B.		<1,790	<477	<478	11,750	0.036	<0.020	0.038	<0.020	<0.036	<0.020	<0.020	<0.020	<1.79	<0.953	<0.956	<0.956
Pressroom		<1,530	<478	2,380	3,820	0.061	<0.020	0.077	0.755	<0.061	<0.020	0.020	<0.020	<1.53	<0.956	<0.953	<0.956
Pressroom basement		<1,500	<473	478	< 956	0.120	<0.020	0.077	0.020	<0.030	<0.020	<0.020	<0.020	<1.50	<0.946	<0.956	<0.956

(continued)

TABLE 6 (continued)

		SANITARY LANDFILL - BACTERIA COUNT/CUBIC METER (Count/m^3) MPN[a]															
		Total plate count				Total coliform				Fecal coliform				Fecal Streptococci			
	Test date	11-29	11-30	12-1		11-29	11-30	12-1		11-29	11-30	12-1		11-29	11-30	12-1	
	Test day	1	2	3		1	2	3		1	2	3		1	2	3	
Upwind		< 478	239	944		0.211	<0.020	<0.020		<0.020	<0.020	<0.020		<0.956	<0.956	<0.944	
Dw - East		<478	239	203		<0.020	<0.020	<0.021		<0.020	<0.020	<0.021		<0.956	<0.956	<1.01	
Dw - Prim		1,430	200	99.7		0.316	0.048	<0.020		0.020	<0.020	<0.020		<0.956	<0.956	<0.99	
Dw - West		<478	1,390	<95.2		3.16	0.048	<0.020		0.325	<0.020	<0.020		<0.956	<0.956	<0.95	
Working face East		2,190	<95.6	1,680		0.536	<0.020	3.16		0.360	<0.020	0.163		<1.09	<0.956	<0.956	
Working face West		<536	143	2,490		<0.021	<0.020	16.3		<0.021	<0.020	16.3		<1.07	<0.956	6.70	
Scale		<478	<95.6	<95.6		0.048	<0.020	<0.020		<0.020	<0.020	<0.020		<0.956	<0.956	<0.956	

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[a] See Appendix C for discussion of analysis methodology.

Testing was carried out at both the incinerator and the processing plant, which are side by side. The processing plant was not in operation during the tests at the incinerator. However, the incinerator was required to be in operation during the tests at the processing plant, and the closeness of these two facilities is such that one cannot be sure that the downwind samplers at the processing plant were not affected by the incinerator. However, the upwind sampler was always located where it would not be affected by the incinerator. It is unlikely that the in-plant samplers at the processing plant were significantly affected by the incinerator because of the layout of the two facilities and the wind direction existing during the tests.

Since the purpose of this program was to compare bacterial levels, the Hi-Vol results shown in Table 6 are expressed in counts per cubic meter of air, at each test site. To facilitate making comparisons using the numerous entries in Table 6, the data are presented in graphical form in Figures 1 through 8. Figures 1 through 4 are for in-plant samples and Figures 5 through 8 for ambient samples. Downwind ambient results shown in Figures 5 through 8 and the respective averages include all three downwind samplers that were in operation on each test day.

The data in Table 6 and Figures 1 through 8 should be utilized only for purposes of making relative comparisons. Individual values should not be considered absolute because the long-term Hi-Vol sampling method may have resulted in a high die-off rate for many types of bacteria collected on the filter during sampling.*

It should also be recognized that property line bacterial levels, as shown in Figures 5 through 8, are not strictly comparable because distances from the source(s) to the property lines were different for each plant and may even have been different on separate test days at any one plant, depending on wind direction. Nevertheless, the purpose of this program was to make relative comparisons based on property line levels, regardless of these distance considerations.

The Hi-Vol data on total bacteria counts, both in-plant and ambient (Figures 1 and 5), show the same general trend; i.e., the processing plant has the highest average count and the landfill, the lowest. In the case of the ambient samples (Figure 5), the processing plant had the highest average downwind value but it also had the highest average upwind value. This fact makes it more difficult to say that the processing plant has a greater effect on downwind bacterial levels than the other types of waste handling facilities.

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* It has been suggested that bacterial growth might occur on the Hi-Vol filters, as opposed to die-off. This may be a possibility but it is considered to be highly unlikely.

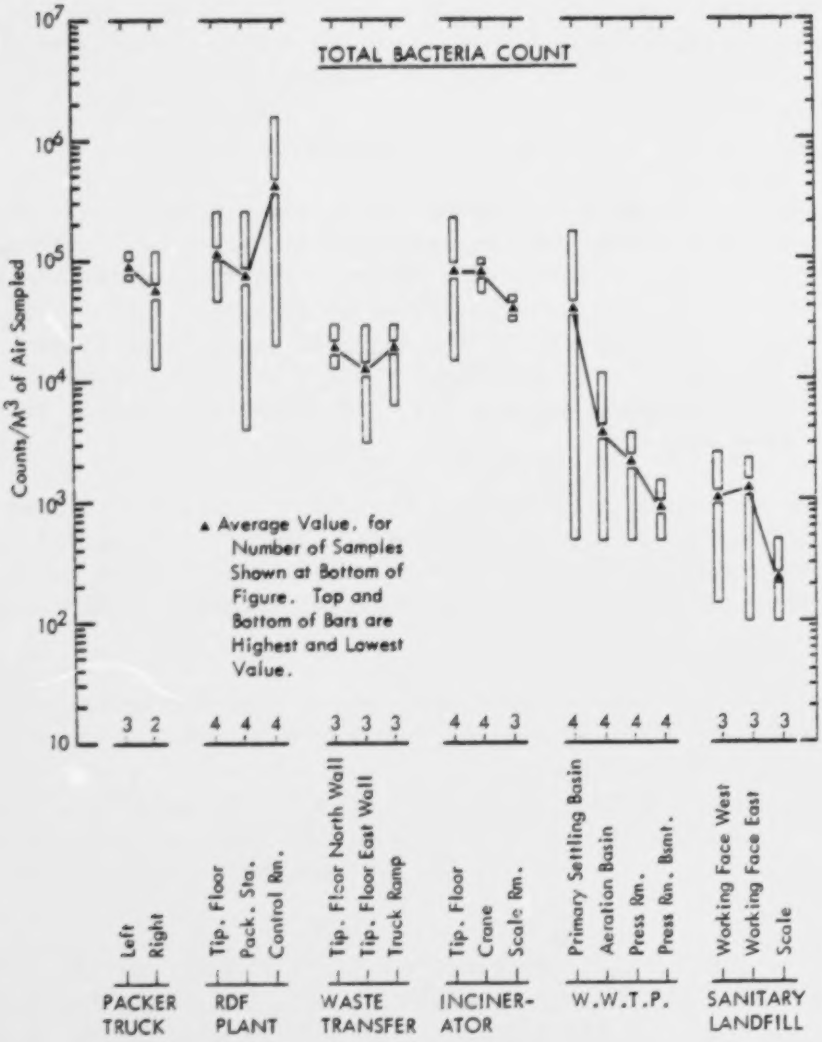

Figure 1. In-plant Hi-Vol samples (total bacteria count).

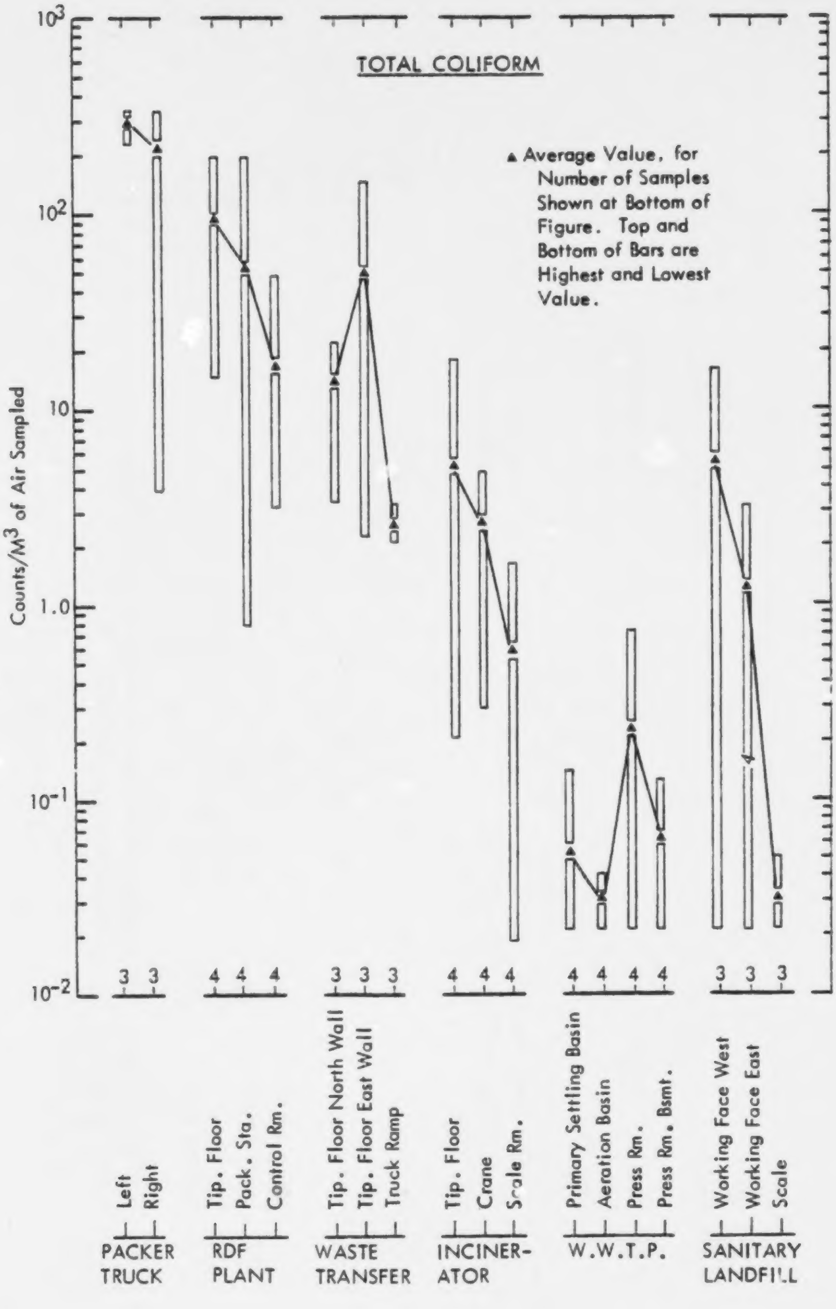

Figure 2. In-plant Hi-Vol samples (total coliform).

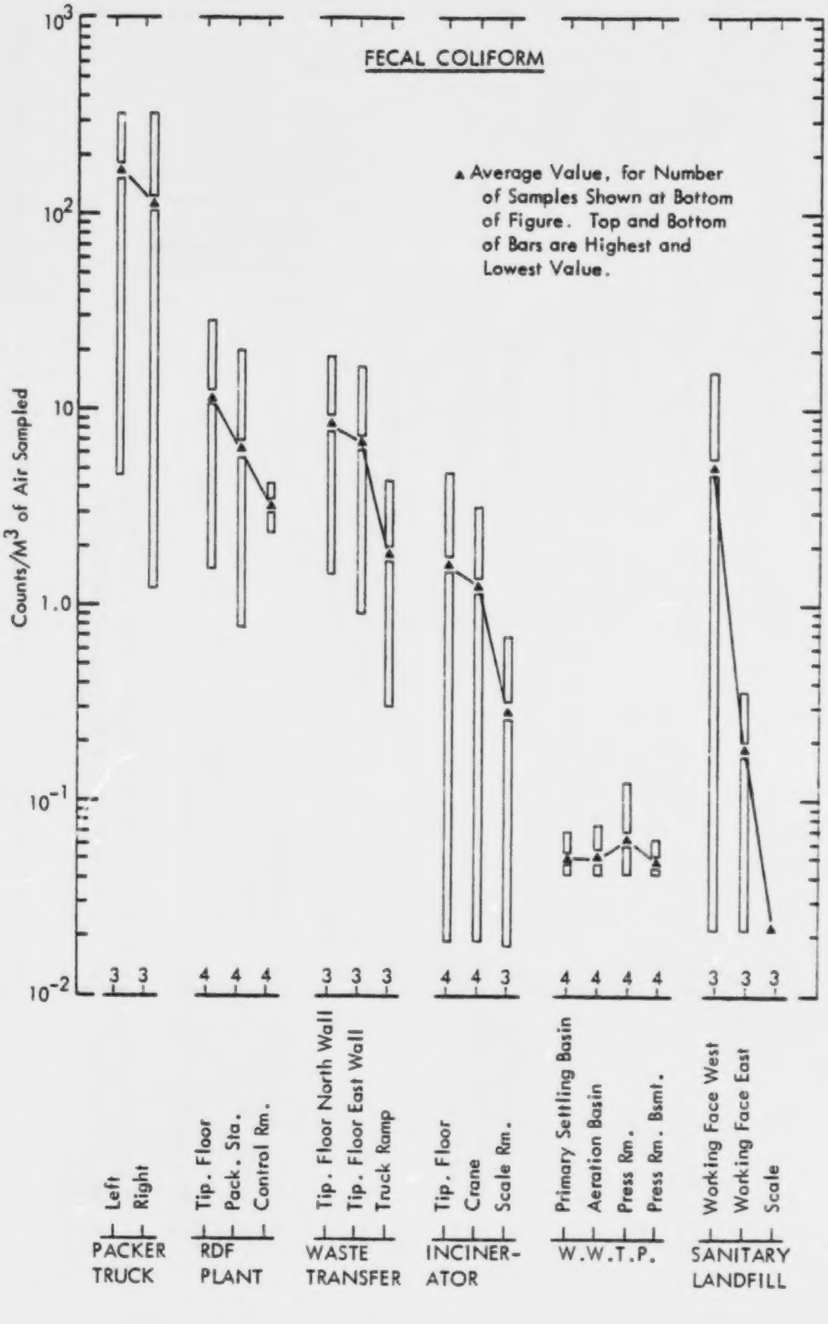

Figure 3. In-plant Hi-Vol samples (fecal coliform).

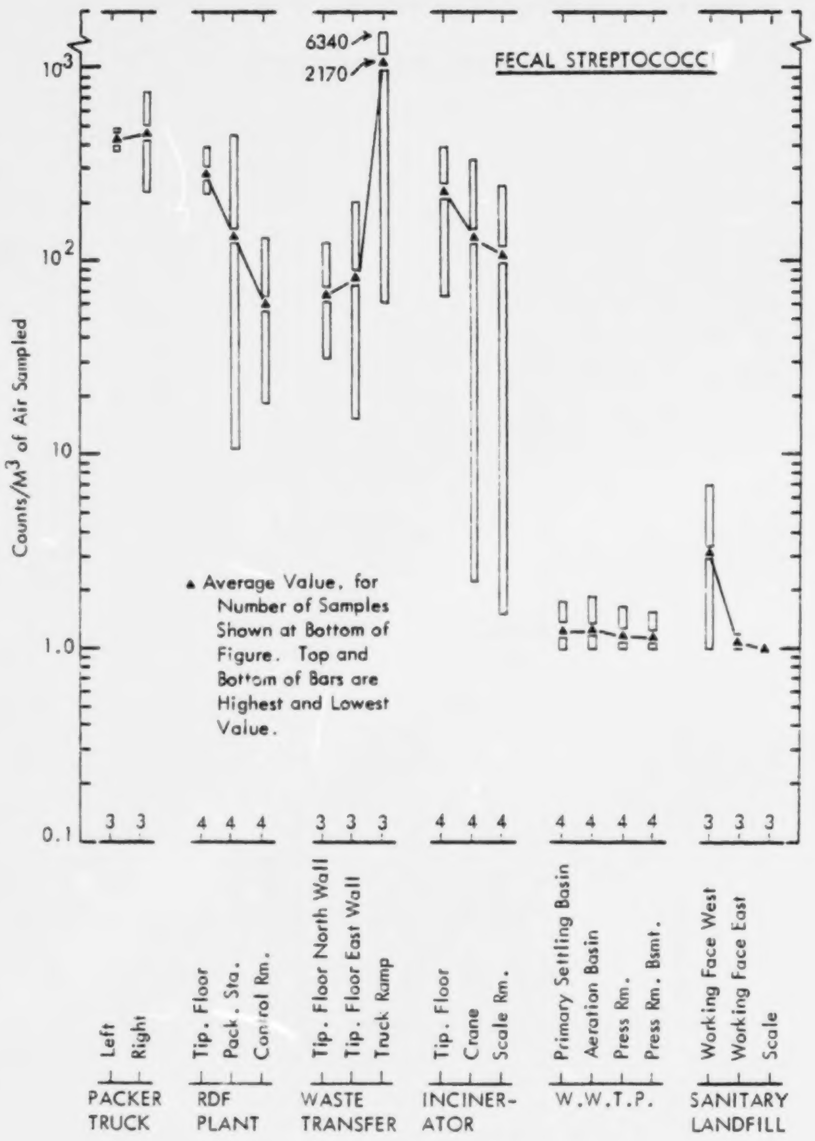

Figure 4. In-plant Hi-Vol samples (fecal streptococci).

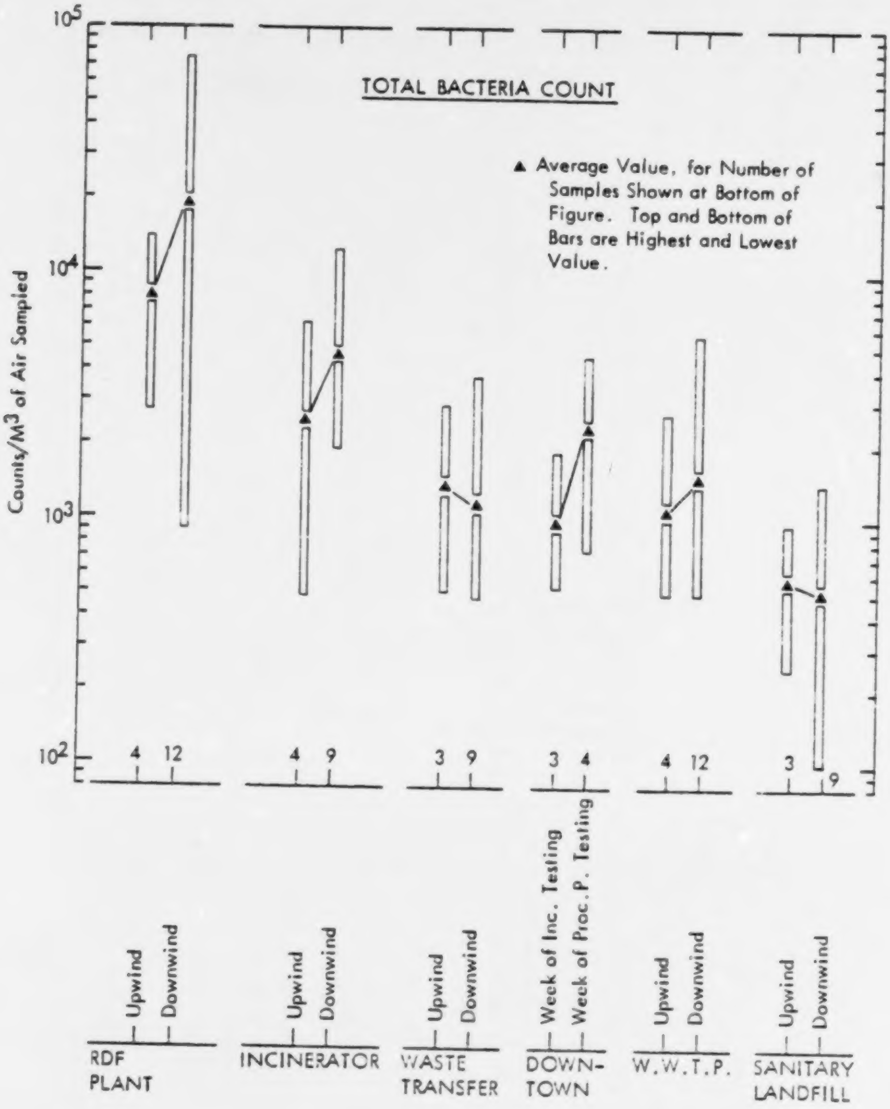

Figure 5. Ambient Hi-Vol samples (total bacteria count).

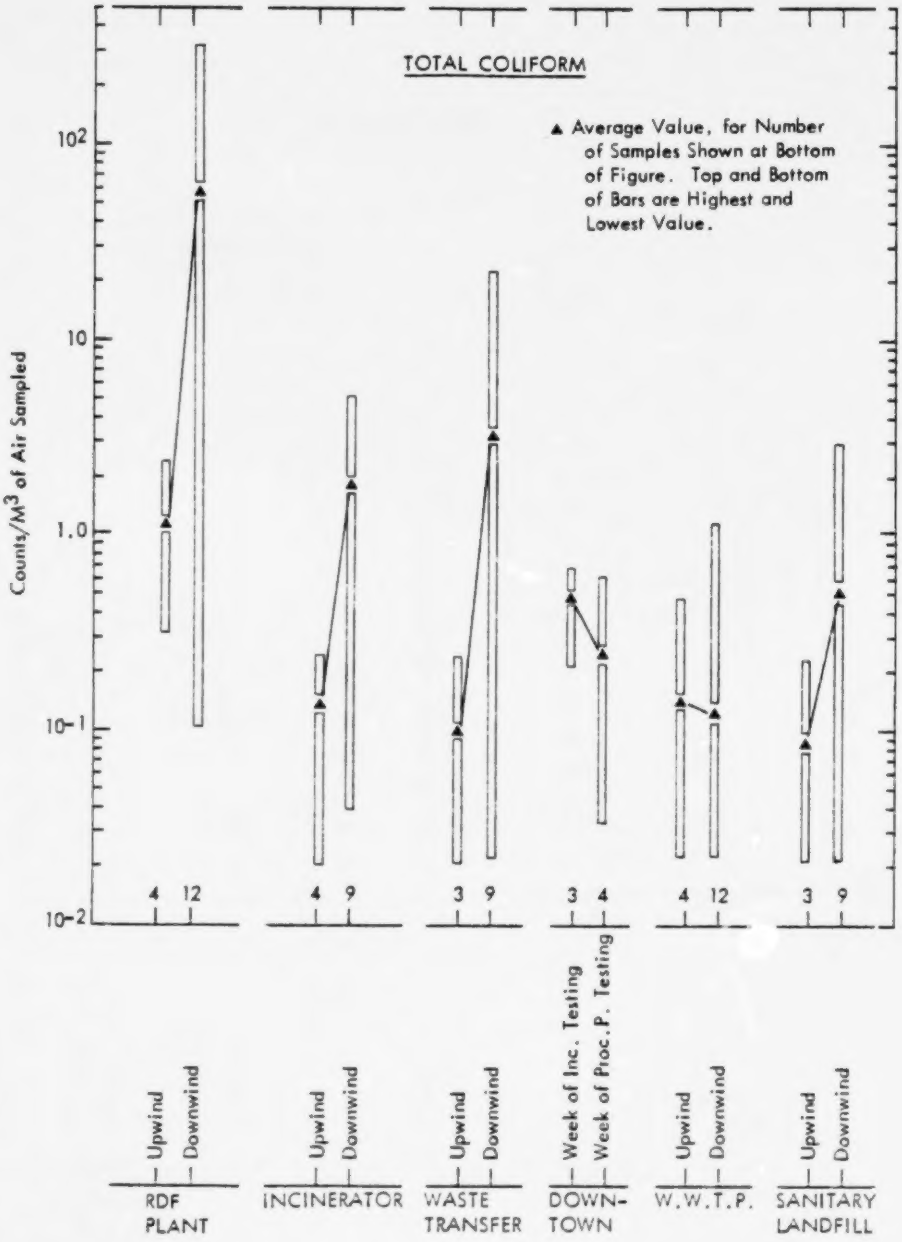

Figure 6. Ambient Hi-Vol samples (total coliform).

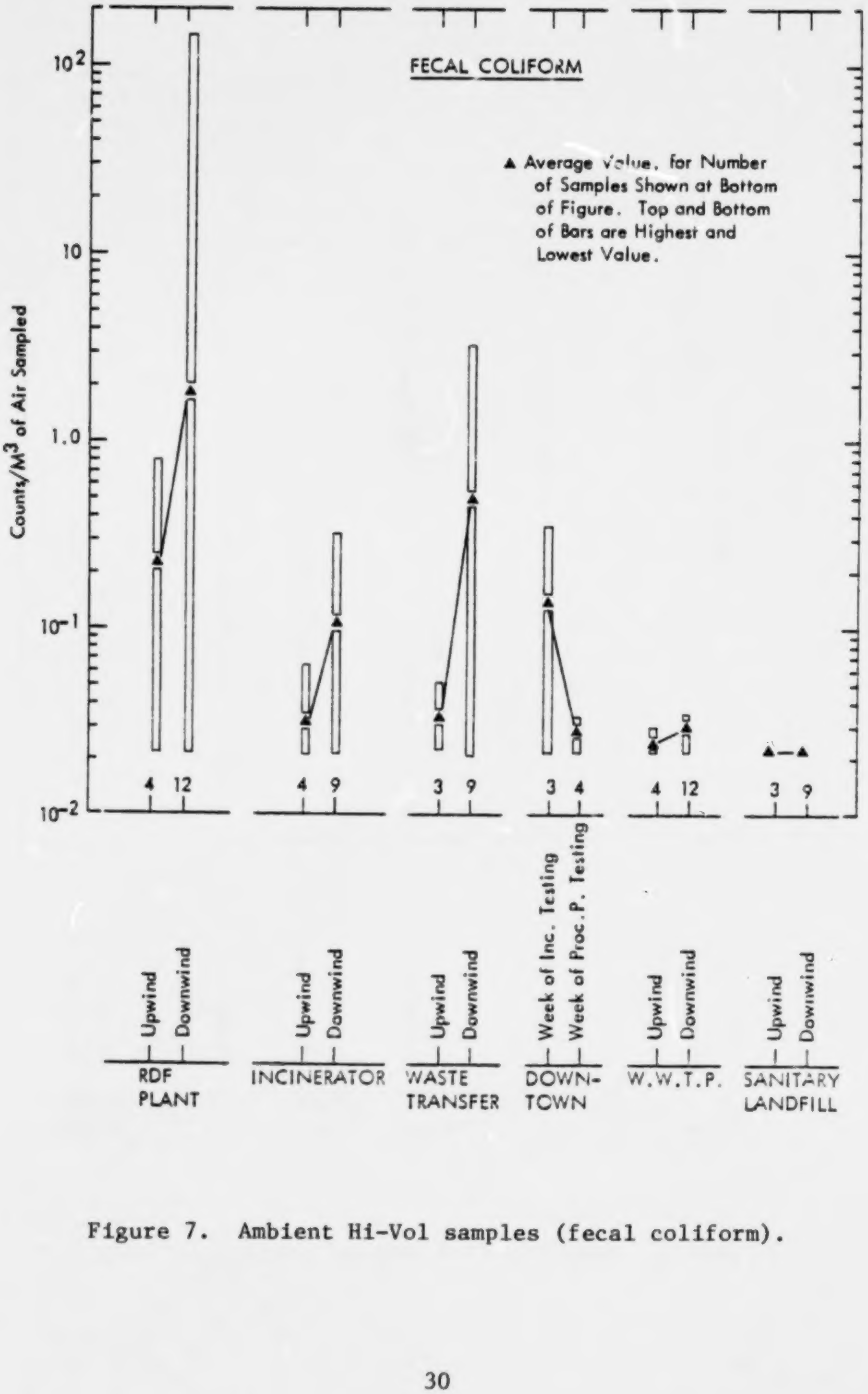

Figure 7. Ambient Hi-Vol samples (fecal coliform).

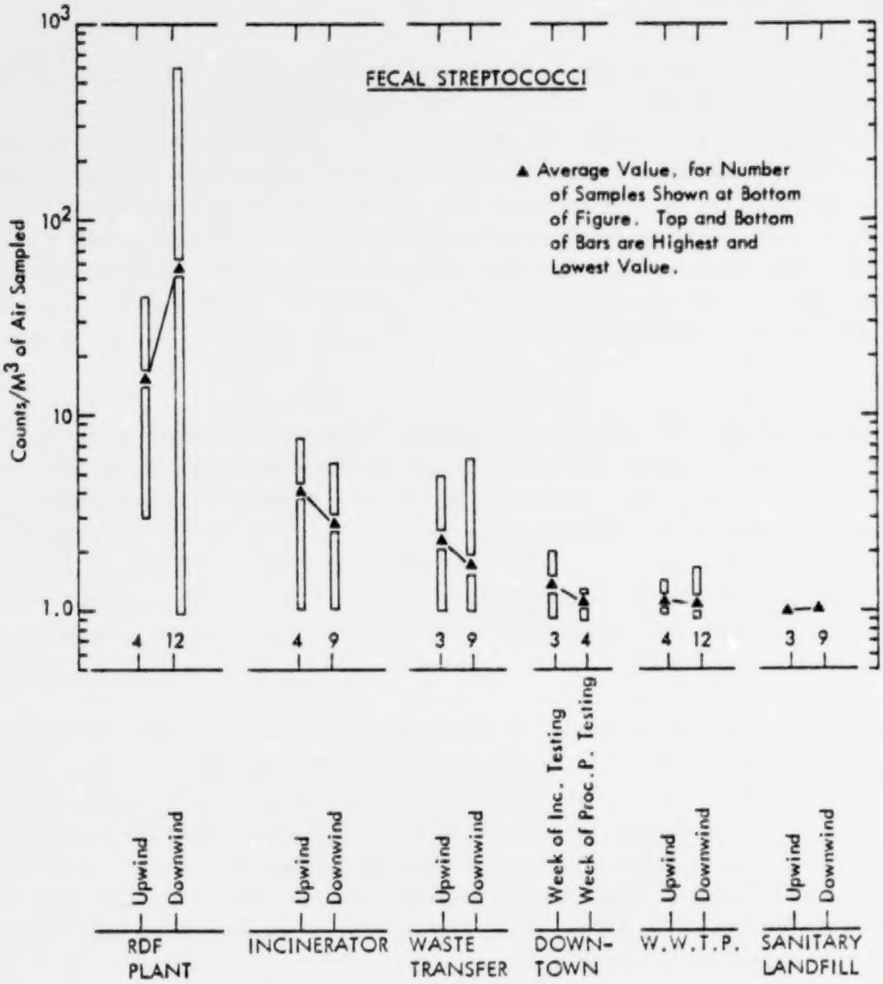

Figure 8. Ambient Hi-Vol samples (fecal streptococci).

It can be seen in Figures 5 through 8 that the processing plant had the highest average downwind levels for all four bacteria groups (total bacteria, total coliform, fecal coliform, and fecal Streptococci) while the sewage treatment plant and landfill generally had the lowest average values for each group.

For purposes of making relative comparisons it is important to note that with the exception of total coliform, the upwind and downwind levels were about the same for the sewage treatment plant and the landfill. By contrast, the average downwind values for the processing plant were always higher than the upwind values for all four bacteria groups. With one exception (fecal Streptococci) the average downwind value for the incinerator was higher than the upwind value. The waste transfer station indicated a higher average downwind value for two of the groups. Table 7 presents a rank ordering of the plants based on both ambient and in-plant Hi-Vol results for each bacteria group.

The in-plant Hi-Vol results (Figures 1 through 4) show roughly the same relative relationship from plant to plant as did the ambient Hi-Vol results. However, the in-plant sites include the packer truck, which turned out to show bacterial levels comparable with the highest of the other locations that were actually located within a plant. Although workers in the RDF plant may be exposed to bacterial levels somewhat higher than at the incinerator (e.g., fecal coliform), they are about the same as, or lower than, those to which the packer truck operators may be exposed.

A comparison of the average values of the in-plant and ambient Hi-Vol data for each plant tested is shown in Figures 9 through 12. This comparison does show that the in-plant bacterial levels were generally higher than, or about equal to, the ambient downwind levels. Notably, the in-plant values for total bacteria count at the RDF plant, incinerator, and waste transfer station were considerably higher than the downwind values. The in-plant and downwind Hi-Vol samples at the RDF plant were about the same order of magnitude for the other three groups of bacteria.

Andersen samples--Andersen agar plate impactor tests were made during each test day at each plant, at the same locations as the Hi-Vol samplers, in order to obtain additional data relative to the size distribution of bacteria containing particles (total bacteria count on each stage). Results of those tests are given in Table 8. These results do, in general, show higher colony counts on each stage for the in-plant samples than for the upwind samples.

TABLE 7. RANKING BASED ON AVERAGE BACTERIAL LEVELS IN DESCENDING ORDER FOR HI-VOL TESTING SITES

	Total bacteria count	Total coliform	Fecal coliform	Fecal Streptococci
	In-plant samples			
	RDF plant	Packer truck	Packer truck	Waste transfer
	Packer truck	RDF plant	RDF plant	Packer truck
	Incinerator	Waste transfer	Waste transfer	RDF plant
	Waste transfer	Incinerator	Incinerator	Incinerator
	WWTP	Landfill	Landfill	Landfill
	Landfill	WWTP	WWTP	WWTP
	Ambient samples			
Upwind (and downtown)	RDF plant	RDF plant	RDF plant	RDF plant
	Incinerator	Downtown	Downtown	Incinerator
	Downtown	Incinerator	Waste transfer	Waste transfer
	Waste transfer	WWTP	Incinerator	Downtown
	WWTP	Waste transfer	WWTP	WWTP
	Landfill	Landfill	Landfill	Landfill
Downwind (and downtown)	RDF plant	RDF plant	RDF plant	RDF plant
	Incinerator	Waste transfer	Waste transfer	Incinerator
	Downtown	Incinerator	Incinerator	Waste transfer
	WWTP	Landfill	WWTP	Downtown
	Waste transfer	Downtown	Downtown	WWTP
	Landfill	WWTP	Landfill	Landfill

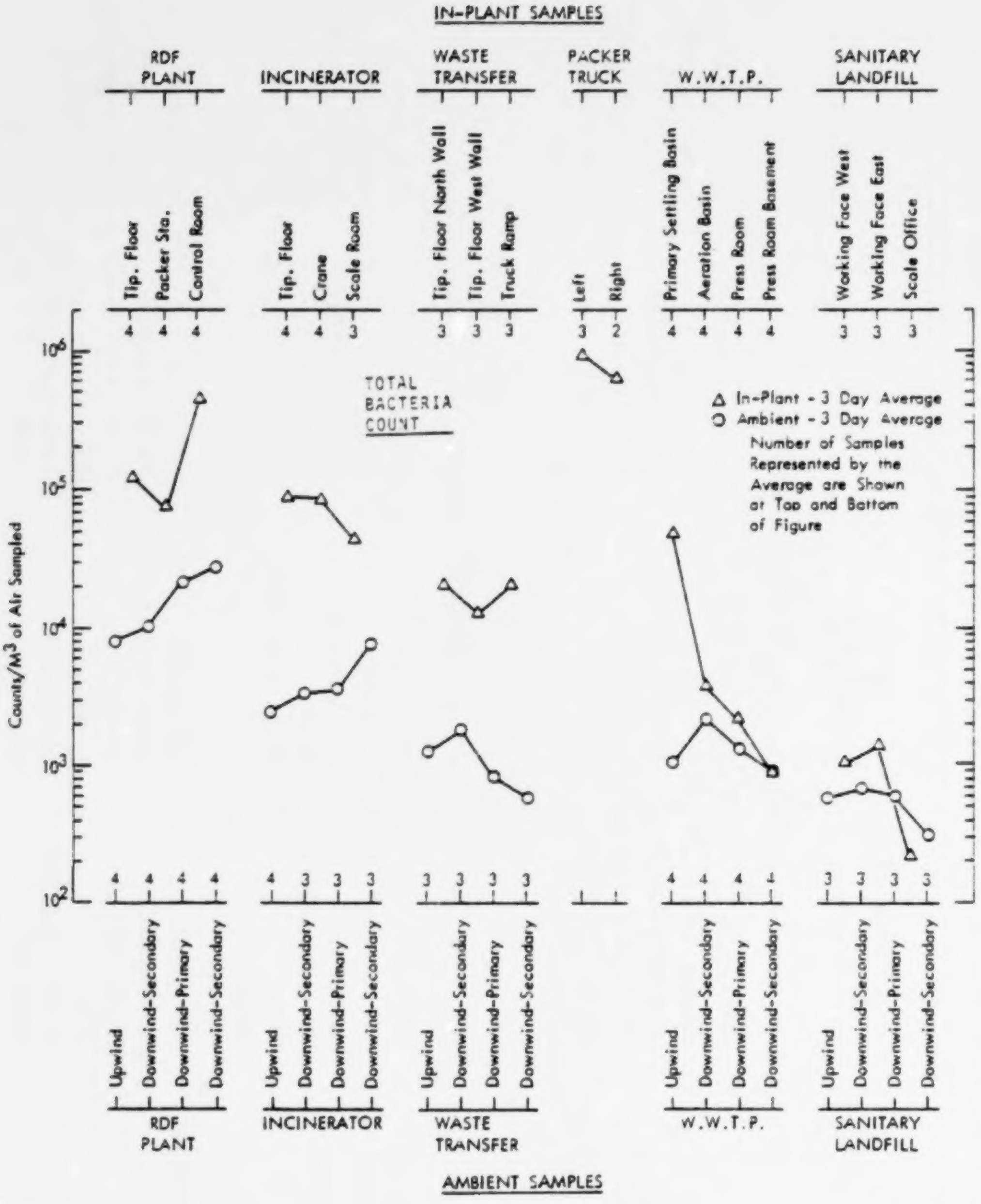

Figure 9. Average in-plant and ambient Hi-Vol results (total bacteria count).

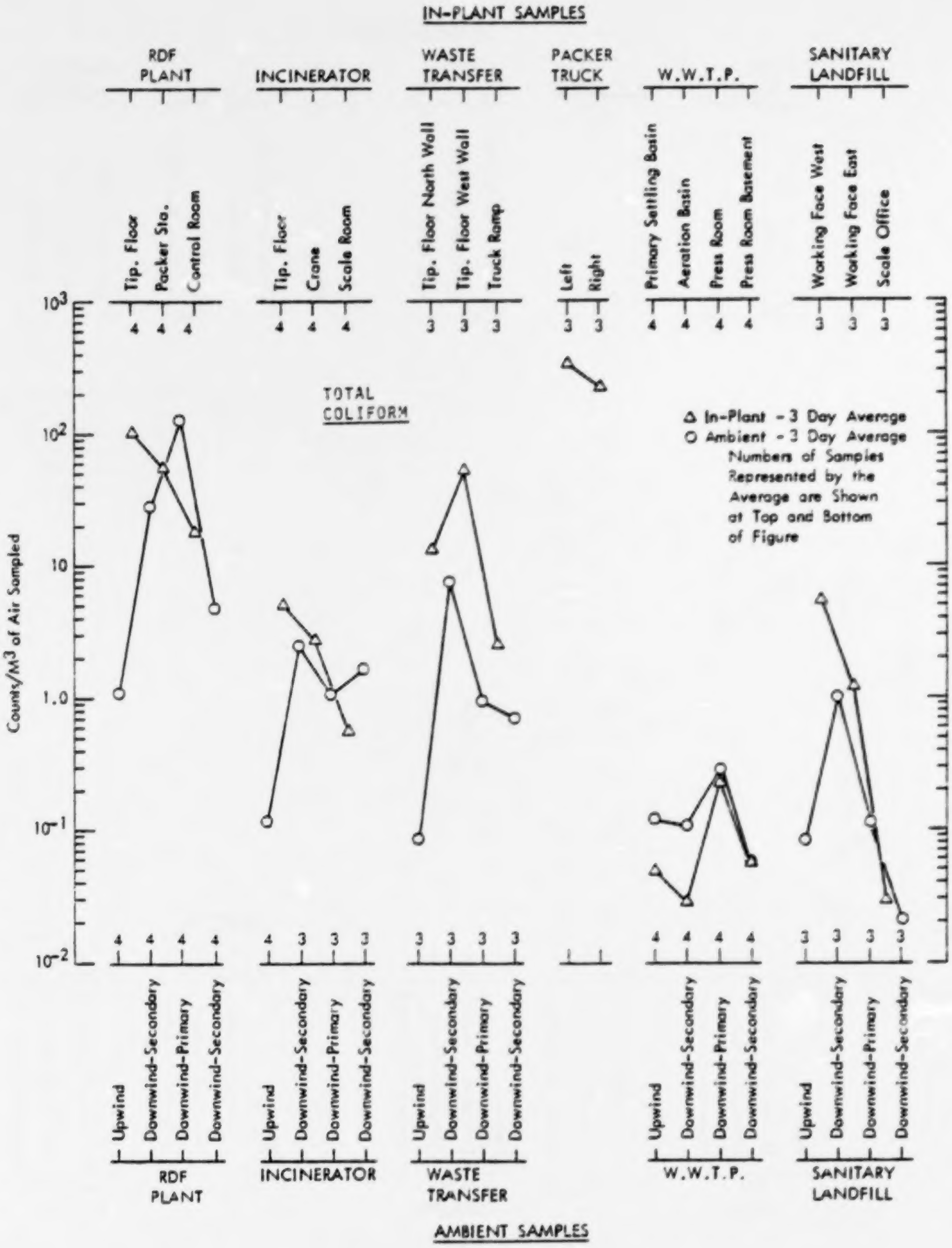

Figure 10. Average in-plant and ambient Hi-Vol results (total coliform).

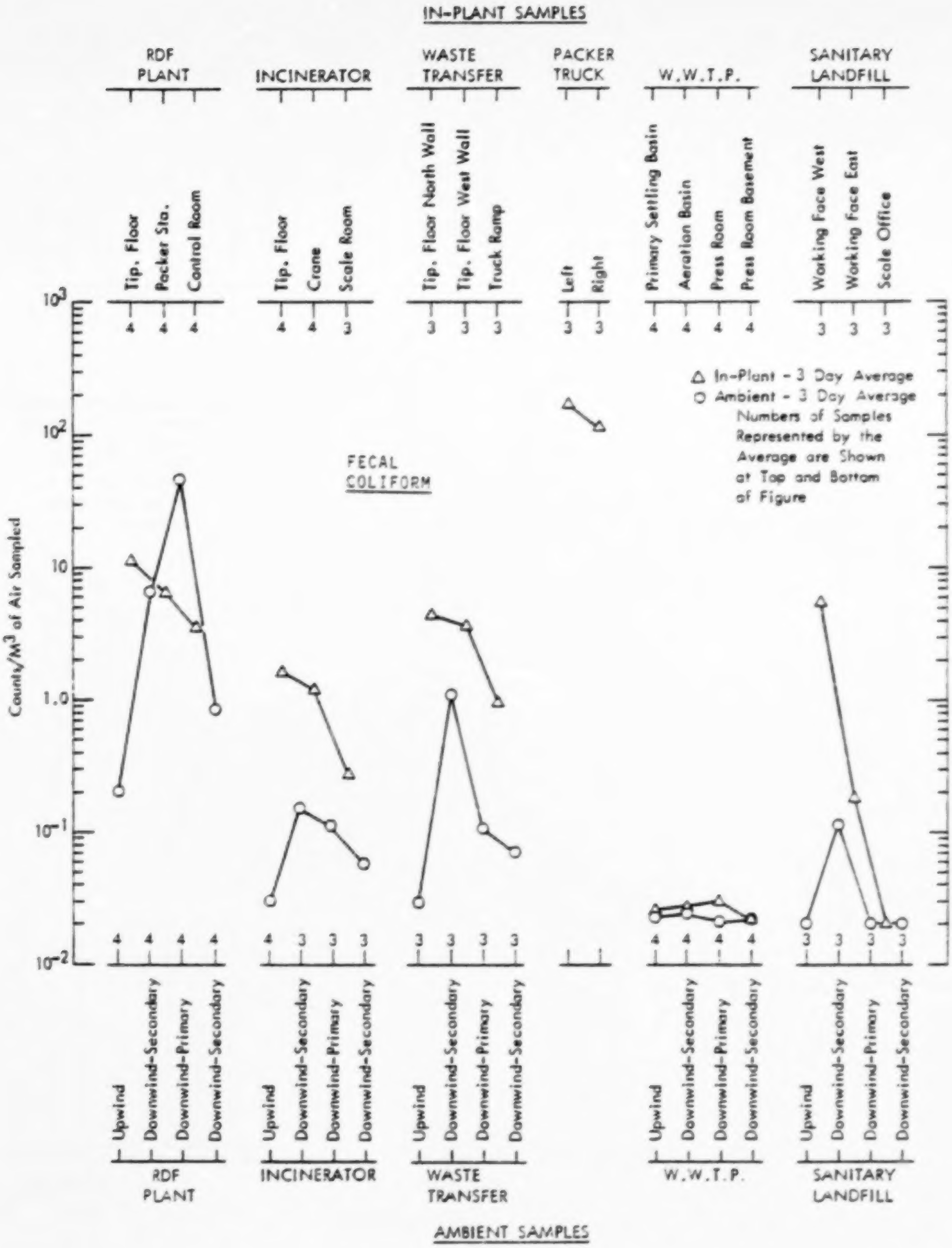

Figure 11. Average in-plant and ambient Hi-Vol results (fecal coliform).

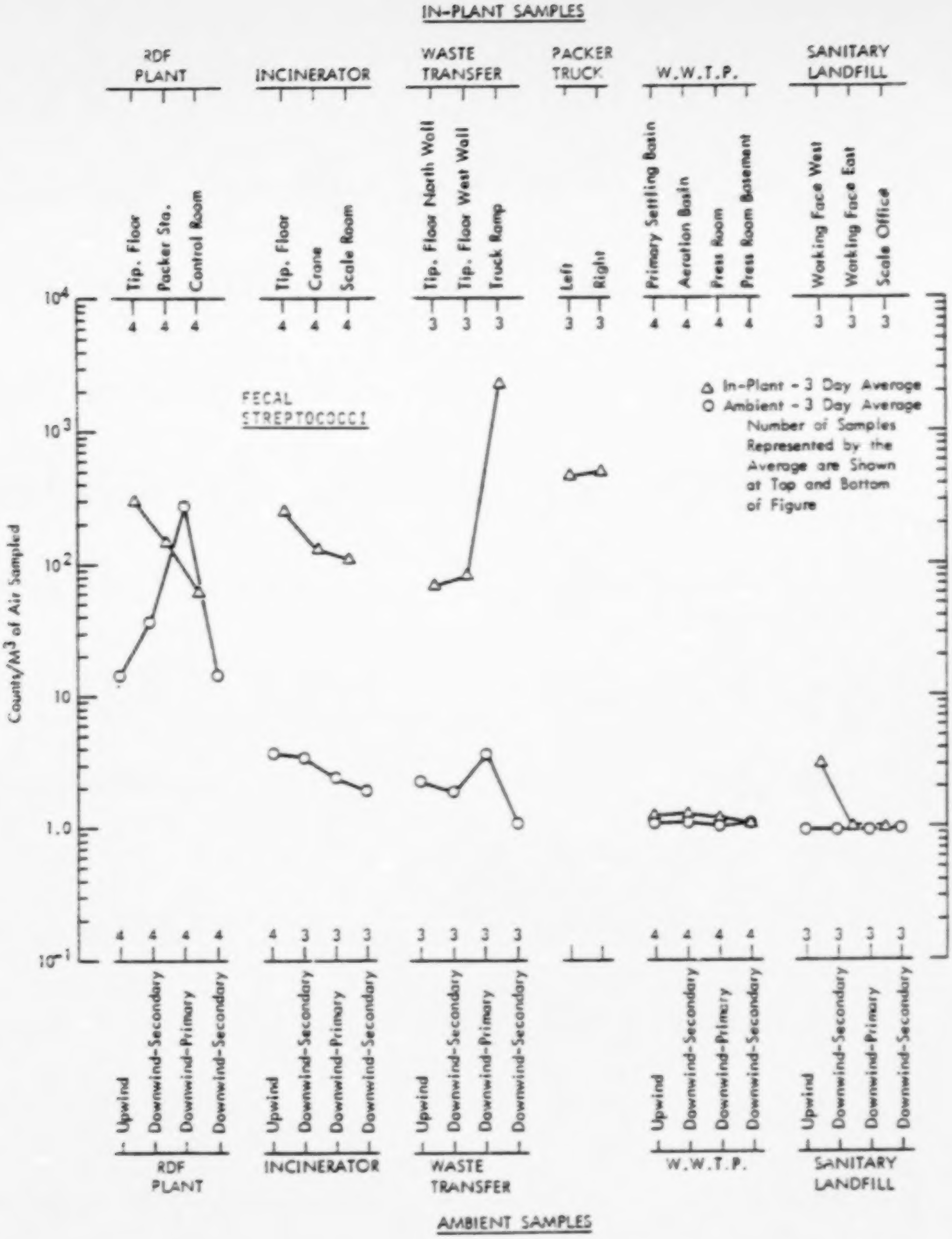

Figure 12. Average in-plant and ambient Hi-Vol results (fecal streptococci).

TABLE 8. ANDERSEN SAMPLES DATA

							Total bacteria count (counts/m³)						
							Stages and particle size (μm)						
Location	Test day	Date	Sample No.	Sample time (min)	Dry bulb (°C)	R.H. (%)	1 ≥ 9.2 μm	2 5.5-9.2	3 3.3-5.5	4 2.0-3.3	5 1.0-2.0	6 ≤ 1.0 μm	Total count/m³
Incinerator Data													
Tipping Floor	0	11/1/76	001	1.0	16	44	2,290.0	1,070.0	1,180.0	1,040.0	751.0	322.0	6,653.0
Upwind	1	11/2/76	005	10.0	21	48	68.0	28.6	32.2	53.6	21.5	7.2	211.0
Downwind	1		006	10.0	21	48	118.0	89.4	85.8	107.0	42.9	7.2	422.0
Tipping Floor	1		002	0.5	17	55	4,860.0	3,720.0	Spreader	1,650.0	3,000.0	4,860.0	18,090.0
Scale Office	1		003	0.5	17	55	644.0	787.0	71.5	572.0	215.0	143.0	2,433.0
Crane	1	11/2/76	004	0.5	-	-	1,860.0	1,430.0	Mold	Mold	501.0	71.5	3,863.0
Upwind	2	11/3/76	008	10.0	14	19	Spreader	415.0	426.0	Mold	154.0	22.0	1,020.0
Downwind	2		007	10.0	11	29	372.0	318.0	243.0	Mold	154.0	25.0	1,112.0
Tipping Floor	2		009	0.5	14	18	6,870.0	Spreader	2,930.0	Mold	1,720.0	787.0	12,307.0
Scale Office	2		010	0.5	14	18	2,000.0	Spreader	715.0	1,860.0	1,360.0	Mold	5,935.0
Crane	2	11/3/76	011	0.5	15	21	5,440.0	3,790.0	3,000.0	Mold	Mold	1,430.0	13,660.0
Upwind	3	11/4/76	012	10.0	3	48	75.0	54.0	89.0	32.0	32.0	4.0	286.0
Downwind	3		013	10.0	3	48	68.0	86.0	47.0	78.0	50.0	4.0	333.0
Tipping Floor	3		015	0.5	6	36	1,650.0	715.0	644.0	429.0	1,220.0	358.0	5,016.0
Scale Office	3		014	0.5	22	19	1,860.0	1,650.0	1,430.0	1,430.0	Mold	1,360.0	6,300.0
Crane	3	11/4/76	016	0.5	6	41	215.0	358.0	Mold	930.0	501.0	2,220.0	4,224.0
RDF Plant													
Upwind	0	11/8/76	020	10.0			290.0	172.0	18.0	140.0	97.0	18.0	735.0
Downwind	0		021	10.0			89.0	54.0	68.0	100.0	36.0	14.0	361.0
Tipping Floor	0		017	0.5	Not Taken		5,870.0	4,860.0	2,000.0	1,430.0	1,220.0	1,220.0	16,600.0
Control Room	0		018	0.5			501.0	715.0	644.0	2,220.0	1,070.0	1,860.0	7,010.0
Packer Station	0	11/8/76	019	0.5			358.0	358.0	4,510.0	358.0	Mold	2,720.0	8,304.0
Upwind	1	11/9/76	022	10.0	13	40	193.0	186.0	365.0	408.0	250.0	21.0	1,423.0
Downwind	1		026	10.0	21	26	225.0	136.0	243.0	89.0	261.0	140.0	1,094.0
Tipping Floor	1		023	0.5	14	37	1,790.0	1,930.0	3,650.0	1,290.0	1,860.0	1,220.0	11,740.0
Control Room	1		024	0.5	22	27	930.0	358.0	1,360.0	858.0	2,070.0	1,570.0	7,146.0
Packer Station	1	11/9/76	025	0.5	16	32	1,290.0	358.0	930.0	644.0	858.0	143.0	4,223.0
Upwind	2	11/10/76	031	10.0	10	38	Spreader	Spreader	222.0	232.0	100.0	21.0	575.0
Downwind	2		030	10.0	11	19	Spreader	Mold	279.0	383.0	200.0	125.0	987.0
Tipping Floor	2		027	0.5	9	37	Mold	5,440.0	4,680.0	Mold	6,440.0	3,500.0	20,060.0
Control Room	2		028	0.5	18	23	1,140.0	2,580.0	1,790.0	2,360.0	1,430.0	1,070.0	10,370.0
Packer Station	2	11/10/76	029	0.5	7	42	501.0	644.0	429.0	286.0	72.0	143.0	2,075.0
Upwind	3	11/11/76	036	10.0	2	45	Spreader	350.0	Spreader	519.0	325.0	190.0	1,384.0
Downwind	3		035	10.0	3	53	443.0	368.0	372.0	497.0	243.0	21.0	3,328.0
Tipping Floor	3		032	0.5	3	53	5,790.0	3,150.0	Mold	Mold	5,510.0	3,150.0	17,600.0
Control Room	3		033	0.5			1,290.0	1,000.0	1,930.0	1,790.0	1,430.0	644.0	8,084.0
Packer Station	3	11/11/76	034	0.5	Not Taken		Mold	2,360.0	2,790.0	1,790.0	Mold	429.0	7,369.0

(continued)

TABLE 8 (continued)

Location	Test day	Date	Sample No.	Sample time (min)	Dry bulb (°C)	R.H. (%)	Total bacteria count (counts/m^3) Stages and particle size (μm) 1 ≥ 9.2 μm	2 5.5-9.2	3 3.3-5.5	4 2.0-3.3	5 1.0-2.0	6 ≤ 1.0 μm	Total count/m^3
Wastewater Treatment													
Upwind	1	11/15/76	054	10.0	9	26	29.0	7.0	7.0	7.0	0.0	57.0	107.0
Downwind	1		051	10.0	8	33	290.0	308.0	165.0	211.0	157.0	125.0	1,256.0
Prim. Set.	1		050	0.5	8	45	215.0	215.0	72.0	143.0	0.0	0.0	645.0
Press Room	1		052	0.5	15	29	0.0	0.0	0.0	0.0	644.0	0.0	644.0
Aeration	1	11/15/76	053	0.5	9	23	2,500.0	1,220.0	1,860.0	2,500.0	1,070.0	0.0	9,150.0
Upwind	2	11/16/76	056	10.0	6	62	7.0	7.0	0.0	0.0	0.0	0.0	14.0
Downwind	2		055	10.0	3	73	29.0	0.0	11.0	0.0	0.0	0.0	40.0
Press Room	2		057	0.5	18	40	0.0	143.0	143.0	143.0	0.0	71.0	500.0
Pr. Rm. Bsmt.	2		058	0.5	15	48	57,200.0	51,500.0	17,800.0	17,900.0	10,500.0	215.0	155,115.0
Prim. Set.	2		059	0.5	12	38	143.0	143.0	71.0	0.0	0.0	0.0	357.0
Aeration	2	11/16/76	060	0.5	12	38	358.0	214.0	143.0	286.0	0.0	0.0	1,001.0
Upwind	3	11/17/76	064	10.0	16	32	36.0	29.0	Mold	89.0	61.0	11.0	226.0
Downwind	3		066	10.0	16	36	68.0	61.0	36.0	46.0	72.0	29.0	315.0
Press Room	3		065	0.5	18	35	501.0	858.0	501.0	572.0	215.0	0.0	2,647.0
Pr. Rm. Bsmt.	3		063	0.5	15	47	TNTC[a]	TNTC[a]	TNTC[a]	22,500.0	6,220.0	286.0	29,006.0
Prim. Set.	3		061	0.5	4	78	Mold	215.0	143.0	286.0	143.0	0.0	787.0
Aeration	3	11/17/76	062	0.5	6	70	71.0	71.0	215.0	286.0	71.0	0.0	714.0
Upwind	4	11/18/76	070	10.0	19	49	89.0	79.0	86.0	Mold	32.0	54.0	340.0
Downwind	4		068	10.0	13	49	161.0	64.0	111.0	Mold	111.0	21.0	468.0
Press Room	4		072	0.5	23	27	715.0	71.0	215.0	286.0	286.0	0.0	1,573.0
Pr. Rm. Bsmt.	4		069	0.5	23	26	9,440.0	9,300.0	12,100.0	12,950.0	7,730.0	1,500.0	53,020.0
Prim. Set.	4		067	0.5	8	60	1,570.0	644.0	358.0	572.0	286.0	143.0	3,573.0
Aeration	4	11/18/76	071	0.5	25	24	215.0	215.0	286.0	143.0	215.0	215.0	1,289.0
Waste Transfer Station Data													
Upwind	1	11/22/76	076	10.0	4	38	125.0	50.0	72.0	50.0	36.0	0.0	333.0
Downwind	1		073	10.0	5	47	18.0	50.0	18.0	46.0	32.0	7.0	171.0
Truck Ramp	1		074	0.5	4	47	TNTC[a]	TNTC[a]	TNTC[a]	5,650.0	6,800.0	2,580.0	15,030.0
Tipping Floor -													
East	1		075	0.5	4	34	143.0	501.0	215.0	71.0	71.0	71.0	1,072.0
North	1	11/22/76	077	0.5	4	46	3,290.0	1,570.0	1,650.0	1,650.0	1,000.0	644.0	9,804.0
Upwind	2	11/23/76	079	10.0	2	82	Spreaders	25.0	57.0	72.0	64.0	21.0	239.0
Downwind	2		082	10.0	3	74	379.0	165.0	125.0	207.0	79.0	21.0	976.0
Truck Ramp	2		080	0.5	5	54	715.0	71.0	71.0	0.0	0.0	0.0	857.0
Tipping Floor													
East	2		081	0.5	6	70	TNTC[a]	Spread	Spread	Spread	14,200.0	14,700.0	28,900.0
North	2	11/23/76	078	0.5	2	82	3,290.0	1,570.0	1,860.0	1,500.0	429.0	215.0	8,864.0

(continued)

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TABLE 5 (continued)

Location	Test day	Date	Sample No.	Sample time (min)	Dry bulb (°C)	R.H. (%)	Total bacteria count (counts/m³) Stages and particle size (µm) 1 > 9.2 µm	2 5.5-9.2	3 3.3-5.5	4 2.0-3.3	5 1.0-2.0	6 ≤ 1.0 µm	Total count/m³
Waste Transfer Station Data (Continued)													
Upwind	3	11/24/76	087	10.0	16	36	72.0	72.0	75.0	36.0	18.0	21.0	294.0
Downwind	3	↓	086	10.0	17	34	191.0	Spread	190.0	Spread	107.0	29.0	519.0
Truck Ramp	3	↓	084	0.5	12	42	Spread	Mold	2,150.0	Mold	Mold	715.0	2,865.0
Tipping Floor													
East	3	↓	083	0.5	10	43	Spread	1,650.0	2,500.0	1,650.0	1,070.0	215.0	7,085.0
North	3	11/24/76	085	0.5	16	35	1,160.0	1,000.0	1,930.0	858.0	787.0	71.0	5,806.0
Sanitary Landfill Data													
Upwind	1	11/29/76	094	10.0	-4	72	82.0	36.0	29.0	46.0	11.0	18.0	222.0
Downwind	1	↓	090	10.0	-2	66	39.0	11.0	18.0	29.0	14.0	7.0	118.0
Scale Office	1	↓	091	0.5	-4	72	6,580.0	429.0	572.0	787.0	215.0	71.0	8,654.0
Working Face													
East	1	↓	092	0.5	-4	72	215.0	143.0	143.0	143.0	71.0	0.0	715.0
West	1	11/29/76	093	0.5	-4	61	71.0	71.0	71.0	0.0	143.0	0.0	356.0
Upwind	2	11/30/76	096	10.0	-1	56	82.0	14.0	21.0	7.0	29.0	18.0	171.0
Downwind	2	↓	098	10.0	0	68	211.0	61.0	Spread	82.0	29.0	14.0	397.0
Scale Office	2	↓	095	0.5	-7	69	215.0	71.0	143.0	0.0	0.0	0.0	429.0
Working Face													
East	2	↓	099	0.5	0	68	71.0	71.0	215.0	71.0	358.0	286.0	1,072.0
West	2	11/30/76	097	0.5	-1	56	215.0	71.0	215.0	143.0	0.0	71.0	715.0
Upwind	3	12/1/76	100	10.0	-3	63	68.0	18.0	0.0	11.0	4.0	4.0	105.0
Downwind	3	↓	103	10.0	-1	67	36.0	14.0	7.0	21.0	7.0	0.0	85.0
Scale Office	3	↓	101	0.5	-3	63	501.0	358.0	143.0	71.0	71.0	0.0	1,144.0
Working Face													
East	3	↓	104	0.5	-	-	787.0	358.0	215.0	644.0	215.0	358.0	2,577.0
West	3	12/1/76	102	0.5	-1	67	286.0	215.0	71.0	0.0	71.0	71.0	714.0

a/ TNTC = Too numerous to count.

As far as the distribution of counts on each stage is concerned, the results at first seem to show, unexpectedly, a rather erratic distribution rather than decreasing counts with decreasing size. Certainly, if one were measuring size distribution based on mass of particles, there would normally be less mass of smaller particles present than of larger ones. At the same time, however, the number of smaller particles could still be the same as, or greater than, the number of larger particles. Also, it is theorized that bacteria are not free-floating but are carried in air by carrier particulate matter. In view of this, the results in Table 8 should not be unexpected because the agar impactor test is more indicative of the number of particles containing bacteria within each size range rather than the mass of the particles. Consequently, these data tend to show that the air sampled at most locations did not contain decreasing numbers of bacteria with decreasing size. Thus, a receptor breathing such air might have most of the larger particles removed in the nasal passages, but the number of bacteria containing particles penetrating further into the respiratory tract would not be reduced to the same degree. However, little can be said about the number of bacteria associated with each particle size because the Andersen impactor data are not indicative of the number of bacteria associated with each particle. That is, one large particle and one small particle could well contain grossly different numbers of bacteria but each would still produce only one colony count on the two respective agar impactor stages.

A comparison of the Andersen data for each plant was made in a manner similar to that discussed above for the Hi-Vols. A direct comparison of Andersen data with Hi-Vol data was not valid because the Andersen agar impactor sampling involved much lower sampling rates and sampling times than the Hi-Vol.

A comparison of the ambient and in-plant data for the Andersen samplers is shown in Figures 13 and 14. The ambient data (upwind/downwind) in Figure 13 show the same general trend from plant to plant. The RDF plant has the highest average downwind value. The Andersen data confirm the previous finding from the Hi-Vols, that the RDF plant also had the highest upwind values. The average upwind value at the RDF plant was greater than the average downwind value at any of the other four plants.

In-plant Andersen data (Figure 14) indicate that the number of bacteria containing particles was about the same for the RDF plant, incinerator, and waste transfer station, but was somewhat less for the sewage treatment plant and landfill. The pressroom basement at the treatment plant was one very obvious departure from this. Andersen samples were taken in the pressroom basement during the time filter cake was being dumped and this activity produced the highest values of any in-plant location. A similar effect is not seen in the Hi-Vol results taken at the same location, presumably because the Hi-Vol

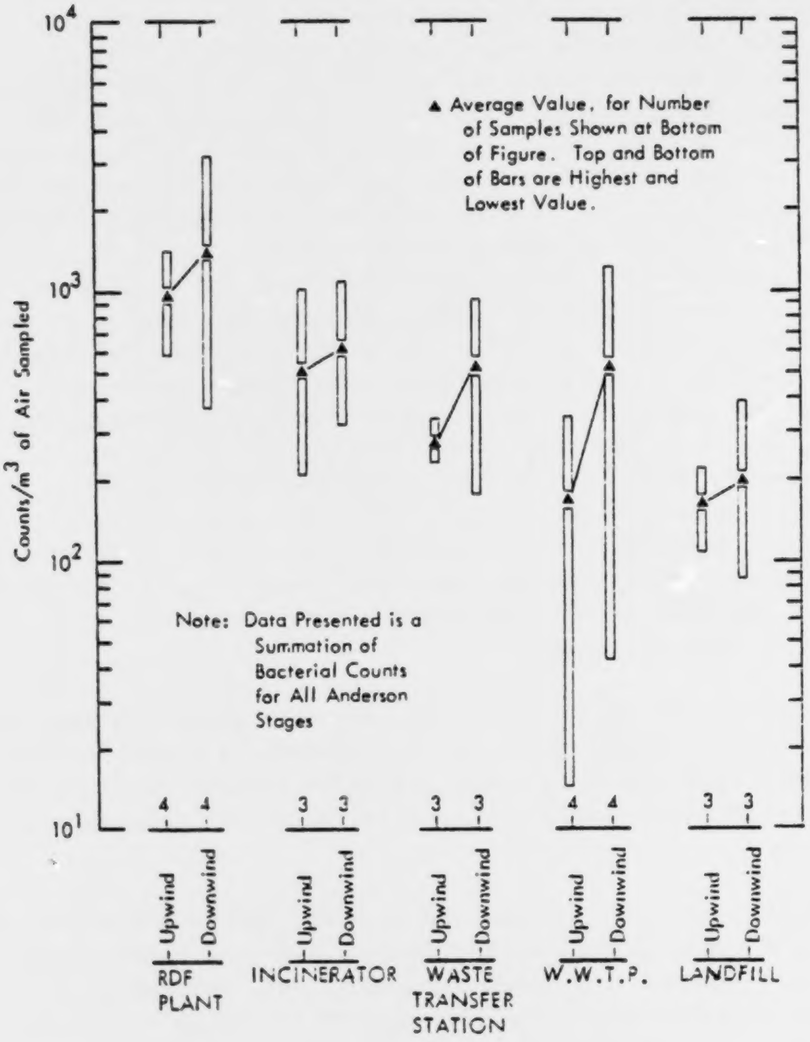


Figure 13. Andersen data for upwind and downwind locations (bacteria - total plate counts).

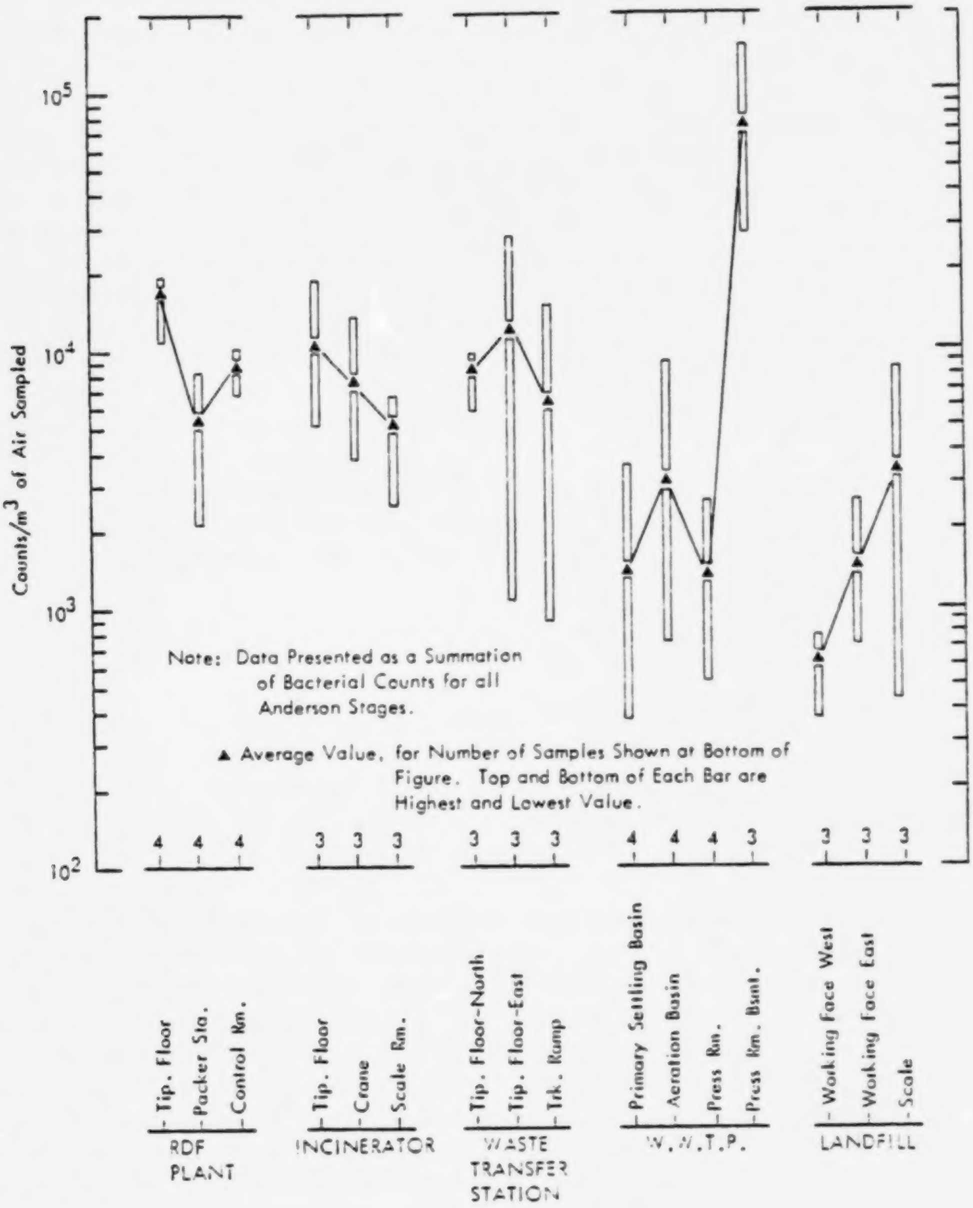


Figure 14. Andersen data for in-plant locations (bacteria - total plate counts).

sampling covers a much longer period of time (6 hr), during most of which the operators are not dumping the cake, so the overall effect is not nearly so great.

Morphological characteristics of bacteria samples--To further categorize the isolates into morphological groups, some of the Hi-Vol and Andersen microbial isolates were examined microscopically to ascertain their morphological characteristics and gram reaction. This was conducted to provide more qualitative information about the microflora contained in the samples. Results of this work are presented in Appendix H. Morphological characteristics were found to consist mainly of gram-positive and gram-negative rods with some gram-negative cocci and also some actinonycetalis, which are predominantly soil type bacteria. The morphological analysis also included culturing of samples on agar plates for future reference and identification if needed.

In an effort to check the preceding observations relative to the Hi-Vol and Andersen bacteria data and to provide a more precise comparison of plants, a statistical analysis of the data was carried out as discussed in the next section.

Statistical Analysis of Hi-Vol and Andersen Bacteria Results--

Evaluation of the test results revealed that there were wide ranges in the bacteria concentrations. In some cases, the individual counts per cubic meter at a particular sampling location varied by several orders of magnitude. A statistical treatment was applied to determine if, in light of this wide variation, differences did exist between the various plants.

Statistical methods used--Because tests at each sampling location were replicated either three or four times, the mean ($\overline{X}$) and the standard deviation (Sx) of the test replications were calculated. The means then were compared to the standard deviations using a curve fit computer program. It was found that the mean was proportional to the standard deviation $[(Sx = k\ (\overline{X})]$ with greater than 90% correlation. Therefore, the distribution was not normal as would be the case if Sx = a constant. It has been postulated by Peterson (4) that the concentrations of microorganisms in solid materials follows a Poisson distribution where $Sx^2 = \overline{X}$. However, this was not the case for the concentrations in air of the species of microorganisms investigated in this study.

Since $Sx = k(\overline{X})$ where k is a constant, the distribution is empirical. To stabilize its variances, the log normal transformation of the test results as recommended by Johnson (5) was performed. Next, an analysis of variance was conducted on the transformed data using an analysis of variance computer program capable of accepting data from unbalanced experimental designs.

For those categories that were statistically significant as shown by the analysis of variance, it was then necessary to perform posteriori tests to distinguish which of the individual categories were different. Winer (6) discusses the various methods, including a method developed by Newman and Keuls that may be used for this purpose. The Newman-Keuls method (modified Q Test) as presented by Snedecor (7) was used because this method gives good protection against erroneous claims of significance.

Statistical comparisons--The primary objective of this research program is to compare the RDF plant to other waste handling facilities as well as to ascertain whether bacteria concentrations differ with particle size. Table 9 lists the comparisons used for the analysis of variance. Analysis of variance was conducted individually for each of the four bacteria species (total bacteria count, total coliform, fecal coliform, and fecal Streptococci) and individually for the Andersen impactor samples, and the Hi-Vol samples for the upwind, downwind, and in-plant locations.

TABLE 9. ANALYSIS OF VARIANCE COMPARISONS

Test	Number of treatments
Andersen impactor	· 6 impactor stages (total bacteria count only)
Hi-Vol sampler	
Upwind	· 5 locales (5 plants)
Downwind	· 6 locales (5 plants and 1 downtown) · 2 sites - primary and secondary (downtown considered a primary site)
In-plant	· 5 locales (5 plants) · 3 sites (receiving area, process area, control area)
Receiving area	· 6 locales (5 plants and 1 packer truck)

Note: Separate comparisons made for total bacteria count, total coliform, fecal coliform, and fecal Streptococci.

For comparative purposes, the downtown location was considered a downwind location because its bacteria concentration could be expected to be affected by the various pedestrian, motor vehicle, and commercial activities in the downtown area. The in-plant sampling locations were divided into three categories of sampling sites: receiving area, process area, and control area. Table 10 presents a listing of the classification of each sampling location.

TABLE 10. CLASSIFICATION OF IN-PLANT LOCATIONS FOR USE AT SITE IN THE ANALYSIS OF VARIANCE

Plant	Site classification		
	Receiving area	Process area	Control area
RDF plant	Tipping floor	Packer station	Control room
Incinerator	Tipping floor	Crane	Scale room
Waste transfer station	Tipping floor - north	Truck ramp	Tipping floor - east
Wastewater treatment plant	Primary settling basin	Aeration basin Pressroom basement	Pressroom
Sanitary landfill	Working face - east Working face - west		Scale

The sampling location entitled "tipping floor - east" at the waste transfer station was separated from the main tipping floor by a half-wall approximately 1.5 m high. Several electrical controls and a stairway leading to the truck ramp were at this location. Therefore, it was classified as a control area, although the operation of the plant did not require this area to be occupied a high percentage of the plant operating time. The sampling location entitled "pressroom" at the wastewater treatment plant was a location adjacent to the operator's control panel. While it was physically in the pressroom, it was classified as a control area. Because the packer truck involved no process or control areas, a separate comparison was made. The packer truck results were included only with the plant receiving areas to determine if significant differences exist.

Statistical results--The analysis of variance performed on the Andersen impactor data showed that the total bacteria count is not a function of particle size. The F-ratio calculated from the analysis of variance was 1.27 for impactor stages, and at the 95% confidence level there was no significant difference in counts per stage for the Andersen impactor samples. Therefore, the number of bacteria containing particles in air are randomly dispersed throughout the particle size range represented by the Andersen stages, which is from 1 µm to greater than 7 µm.

Table 11 presents the results of the analysis of variance of the Hi-Vol samples. At the 95% confidence level, there is a significant difference between locales (plants) for all bacteria species and all tests. The one exception is fecal coliform where there is no significant difference between plants for upwind samples.

For the downwind and in-plant tests where two levels of treatment (locale and site) were examined, there was no significant difference due to site for all bacteria samples. The single exception was fecal Streptococci for downwind samples. For downwind samples, the site was composed of primary samples versus secondary samples. An analysis of the individual fecal Streptococci results from each test day revealed that there was little difference between primary downwind and secondary downwind samples except for the RDF plant. The primary downwind values were much higher on test days 2 and 3 at the RDF plant. These two test days were sufficient to raise the mean value to 256 counts/m^3 versus a mean value of 26 counts/m^3 for the downwind secondary samples. Thus, the analysis of variance showed a significant difference due to site.

Because there were significant differences due to locale, the Q test was used next to determine what individual locales were different from each other and were causing the analysis of variance to show that locale has a significant effect. Figures 15 through 18 present the results of the Q test, showing at the 95% confidence level which plants are significantly different from each other.

TABLE 11. RESULTS OF ANALYSIS OF VARIANCE FOR HI-VOL SAMPLES

Test	Bacteria Species	Treatment	F value	Statistically significant at 95% confidence level
Upwind	Total bacteria count	Locale	4.34	yes
	Total coliform	Locale	4.00	yes
	Fecal coliform	Locale	1.14	no
	Fecal Streptococci	Locale	4.53	yes
Downwind	Total bacteria count	Locale	17.81	yes
	Total coliform	Locale	12.46	yes
	Fecal coliform	Locale	7.58	yes
	Fecal Streptococci	Locale	35.40	yes
Downwind	Total bacteria count	Site	0.14	no
	Total coliform	Site	0.50	no
	Fecal coliform	Site	0.46	no
	Fecal Streptococci	Site	3.53	yes
In-Plant	Total bacteria count	Locale	29.21	yes
	Total coliform	Locale	29.14	yes
	Fecal coliform	Locale	23.22	yes
	Fecal Streptococci	Locale	37.46	yes
In-Plant	Total bacteria count	Site	0.73	no
	Total coliform	Site	1.53	no
	Fecal coliform	Site	0.93	no
	Fecal Streptococci	Site	1.72	no
Receiving Area	Total bacteria count	Locale	3.86	yes
	Total coliform	Locale	12.77	yes
	Fecal coliform	Locale	6.49	yes
	Fecal Streptococci	Locale	107.01	yes

▨ = Statistically Significant Difference at the 95% Confidence Level
PP = RDF Processing Plant
INC = Incinerator
WTS = Waste Transfer Station
SL = Sanitary Landfill
WWTP = Waste Water Treatment Plant
PKTK = Packer Truck

Total Bacteria Count [a]

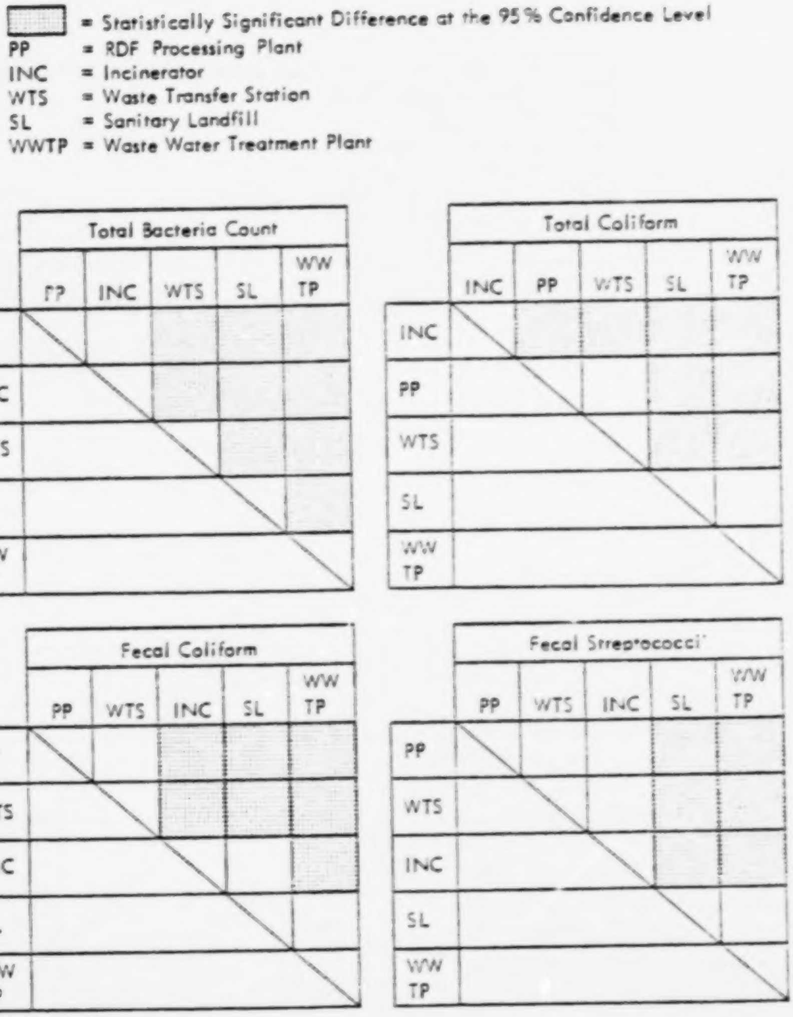
	Total Coliform					
	PP	PKTK	WTS	INC	SL	WW TP
PP				▨	▨	▨
PKTK				▨	▨	▨
WTS					▨	▨
INC						▨
SL						
WW PT						

	Fecal Coliform					
	PKTK	PP	WTS	INC	SL	WW TP
PKTK					▨	▨
PP						▨
WTS						▨
INC						
SL						
WW PT						

	Fecal Streptococci					
	PP	INC	PKTK	WTS	SL	WW TP
PP				▨	▨	▨
INC				▨	▨	▨
PKTK				▨	▨	▨
WTS					▨	▨
SL						
WW PT						

[a] No Difference Between Locations for Total Bacteria Count

Figure 15. Summary of statistical difference between plants for receiving area Hi-Vol samples



▨ = Statistically Significant Difference at the 95% Confidence Level
PP = RDF Processing Plant
INC = Incinerator
WTS = Waste Transfer Station
SL = Sanitary Landfill
WWTP = Waste Water Treatment Plant

	Total Bacteria Count				
	PP	INC	WTS	SL	WW TP
PP			▨	▨	▨
INC			▨	▨	▨
WTS				▨	▨
SL					▨
WW TP					

	Total Coliform				
	INC	PP	WTS	SL	WW TP
INC		▨	▨	▨	▨
PP				▨	▨
WTS				▨	▨
SL					
WW TP					

	Fecal Coliform				
	PP	WTS	INC	SL	WW TP
PP			▨	▨	▨
WTS			▨	▨	▨
INC					▨
SL					
WW TP					

	Fecal Streptococci				
	PP	WTS	INC	SL	WW TP
PP				▨	▨
WTS				▨	▨
INC				▨	▨
SL					
WW TP					

Figure 16. Summary of statistical difference between plants for in-plant Hi-Vol samples.

▨ = Statistically Significant Difference at the 95% Confidence Level
PP = RDF Processing Plant
INC = Incinerator
WTS = Waste Transfer Station
SL = Sanitary Landfill
WWTP = Waste Water Treatment Plant
DT = Downtown

	Total Bacteria Count					
	PP	INC	SL	WW TP	WTS	DT
PP	╲	▨	▨	▨	▨	▨
INC		╲	▨	▨	▨	▨
SL			╲			▨
WW TP				╲		
WTS					╲	
DT						╲

	Total Coliform					
	PP	INC	WTS	DT	SL	WW TP
PP	╲	▨	▨	▨	▨	▨
INC		╲			▨	▨
WTS			╲			
DT				╲		
SL					╲	
WW PT						╲

	Fecal Coliform					
	PP	INC	WTS	SL	WW TP	DT
PP	╲	▨	▨	▨	▨	▨
INC		╲				
WTS			╲			
SL				╲		
WW TP					╲	
DT						╲

	Fecal Streptococci					
	PP	INC	WTS	SL	WW TP	DT
PP	╲	▨	▨	▨	▨	▨
INC		╲				
WTS			╲			
SL				╲		
WW TP					╲	
DT						╲

Figure 17. Summary of statistical difference between plants for downwind Hi-Vol samples.

▨ = Statistically Significant Difference at the 95% Confidence Level
PP = RDF Processing Plant
INC = Incinerator
WTS = Waste Transfer Station
SL = Sanitary Landfill
WWTP = Waste Water Treatment Plant

Total Bacteria Count	PP	INC	WTS	SL	WW TP
PP			▨	▨	▨
INC					
WTS					
SL					
WW TP					

Total Coliform	PP	INC	WTS	SL	WW TP
PP		▨	▨	▨	▨
INC					
WTS					
SL					
WW TP					

Fecal Coliform[a]

Fecal Streptococci	PP	INC	WTS	SL	WW TP
PP		▨	▨	▨	▨
INC					
WTS					
SL					
WW TP					

[a] No Significant Difference Between Locations for Fecal Coliform

Figure 18. Summary of statistical difference between plants for upwind Hi-Vol samples.

Figure 19 is a summary of these results presented in a different format for clarity where all the data from Figures 15 through 18 are presented in Figure 19.

The following discussion compares the RDF plant to other locales.

Upwind counts per cubic meter of bacteria in air were not affected by the individual plant. However, for total coliform and fecal Streptococci, the RDF plant upwind samples had statistically significantly higher counts than any of the other plants. For total bacteria count, the RDF plant was higher than all other plants except the incinerator. The other four plants were not significantly different from each other for all bacteria species. What affect the higher upwind concentrations at the RDF plant had on the downwind and in-plant samples is unknown.

For downwind samples, the RDF plant had significantly higher concentrations than all other locales for all bacteria species. For total bacteria count and to a lesser extent, for total coliform, there were several significant differences between the other locales. However, for fecal coliform and fecal Streptococci, there were no statistically significant differences between the other locales including the downtown location.

Analysis of the in-plant samples showed several differences between plants for the four bacteria species. The RDF plant was always significantly higher than the sanitary landfill and the wastewater treatment plant for all bacteria species, and higher than the waste transfer station for total bacteria count. However, there was no significant difference between the RDF plant and the incinerator for total bacteria count, and between the RDF plant and the waste transfer station for total coliform and fecal coliform. For fecal Streptococci, there was no statistically significant difference between the RDF plant and both the incinerator and the waste transfer station.

Comparison of the various receiving area locales, including the packer truck, showed that based on the Q test, there was no significant difference between locales for total bacteria count. While the analysis of variance shows that locale has a significant effect, the Q test in this case, was not powerful enough to detect individual differences between plants. The initial analysis of variance or F ratio is a single test statistic for the (composite) hypothesis; $H_o = \mu 1 = \mu 2 = \ldots \mu 6$, where μ = the true population mean. Separation of means procedures (Q test in this case) have, in effect, "padding" built in as protection against Type I errors (declaring a significant difference when in fact none exists) because they necessarily consist of multiple comparisons. Thus, it is quite possible to achieve a significant F ratio yet label no individual differences significant, which is what happened in this case.

COMMENT

Treatments underlined by a common line ▬ do not differ from each other at the 95% confidence level.

Treatments not underlined by a common line are statistically significantly different at the 95% confidence level.

LEGEND

PP = RDF Processing Plant
INC = Incinerator
WTS = Waste Transfer Station
SL = Sanitary Landfill
WWTP = Waste Water Treatment Plant
PKTK = Packer Truck
DT = Downtown
▬ = No Statistical Significant Difference

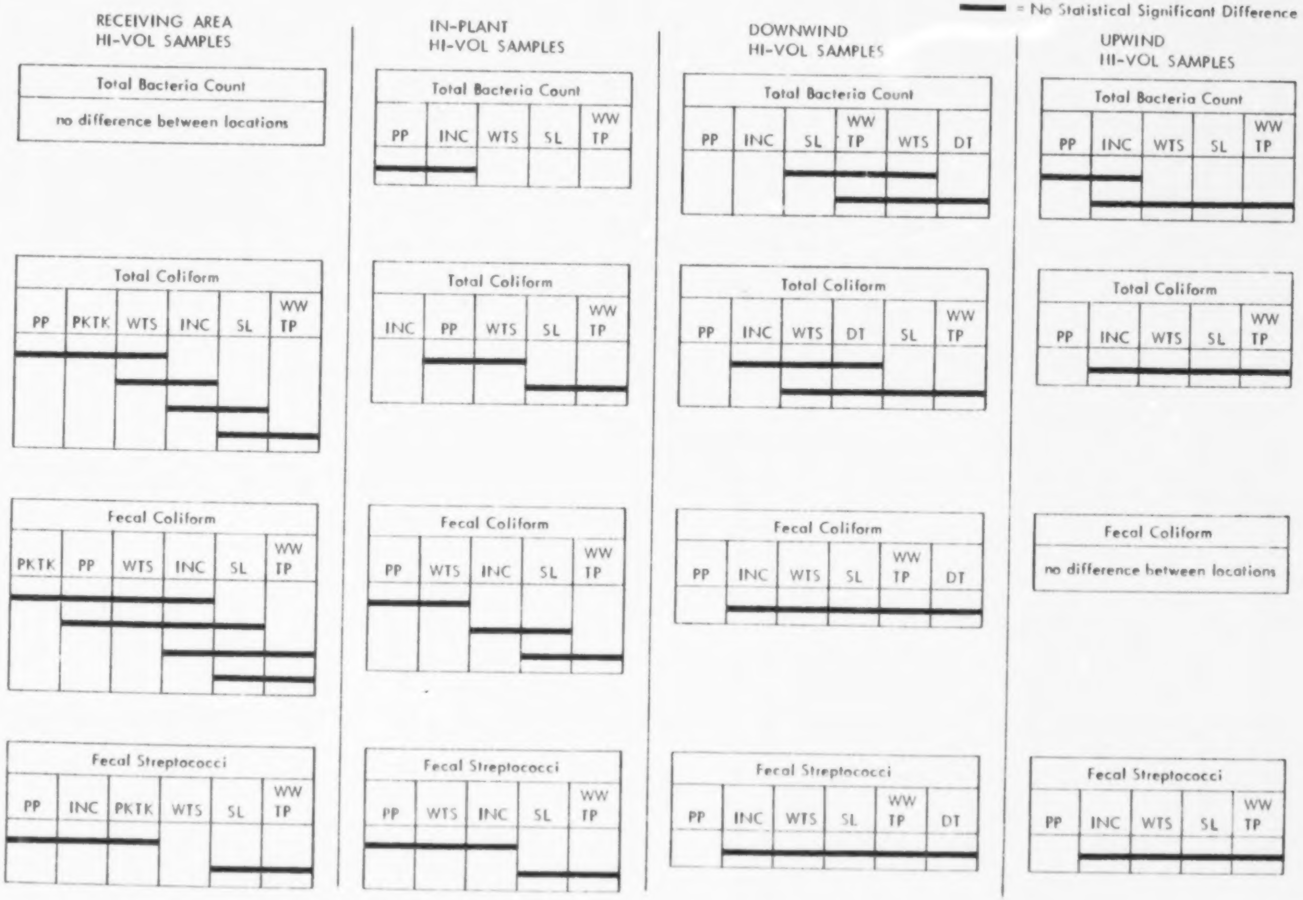

RECEIVING AREA
HI-VOL SAMPLES
Total Bacteria Count
no difference between locations
Total Coliform
PP PKTK WTS INC SL WW TP
Fecal Coliform
PKTK PP WTS INC SL WW TP
Fecal Streptococci
PP INC PKTK WTS SL WW TP
IN-PLANT
HI-VOL SAMPLES
Total Bacteria Count
PP INC WTS SL WW TP
Total Coliform
INC PP WTS SL WW TP
Fecal Coliform
PP WTS INC SL WW TP
Fecal Streptococci
PP WTS INC SL WW TP
DOWNWIND
HI-VOL SAMPLES
Total Bacteria Count
PP INC SL WW TP WTS DT
Total Coliform
PP INC WTS DT SL WW TP
Fecal Coliform
PP INC WTS SL WW TP DT
Fecal Streptococci
PP INC WTS SL WW TP DT
UPWIND
HI-VOL SAMPLES
Total Bacteria Count
PP INC WTS SL WW TP
Total Coliform
PP INC WTS SL WW TP
Fecal Coliform
no difference between locations
Fecal Streptococci
PP INC WTS SL WW TP

Figure 19. Summary of statistical difference between plants.

Analysis of the test results show that the packer truck, the RDF plant, and the incinerator receiving area mean values were similar and were higher than the other plants, and that the sanitary landfill receiving area mean value was lowest. For total coliform concentrations at the receiving areas, there were no significant differences between the RDF plant, the packer truck, and the waste transfer station. There were several other differences between plants. For fecal coliform, in the receiving areas, the RDF plant was not different from any other plant or the packer truck, except the wastewater treatment plant which had lower concentrations.

However, for fecal Streptococci, a known pathogen, the RDF plant receiving area concentrations were not significantly different from either the incinerator receiving area or the packer truck. The sanitary landfill and the wastewater treatment plant had the lowest values.

In summary, concentrations of bacteria in air at the refuse RDF plant were either statistically significantly higher than some of the other locales, or there was no significant difference. The RDF plant concentrations were never significantly lower than any of the other locales. Table 12 is a listing of those plants whose concentrations are not different from those at the RDF plant. Fecal Streptococci was of greatest interest since this species is a known pathogen. While the upwind and downwind fecal Streptococci concentrations were higher at the RDF plant than at any other locale, the RDF plant in-plant concentrations, taken as a group, were not different from the incinerator or the waste transfer station. For the receiving area specifically, the RDF plant fecal Streptococci concentrations were not statistically different from the packer truck or the incinerator.

Finally, all the statistical comparisons were made for only three or four replications of each test. Therefore, the minimum number of replicate samples were taken which would allow statistical comparisons to be made. Because of the wide range of concentrations for some of the tests a greater number of replications for each test condition could possibly result in a change in some of the statistical conclusions made in this report. It is recommended that any future tests be replicated a greater number of times so that statistical analysis can be used more fully.

Interpretation of Bacteria Results--

Interpretation of the bacteria results was based on the previously presented data along with salient information from a search of available literature (Appendix I).

TABLE 12. LOCALES WHOSE BACTERIA CONCENTRATIONS WERE NOT STATISTICALLY DIFFERENT FROM THOSE AT THE RDF PROCESSING PLANT

Test	Total bacteria count	Total coliform	Fecal coliform	Fecal Streptococci
Upwind	Incinerator	-	All	-
Downwind	-	-	-	-
In-plant	Incinerator	Waste transfer station	Waste transfer station	Incinerator Waste transfer station
Receiving area	All	Packer truck Waste transfer station	Packer truck Incinerator Waste transfer station Sanitary landfill	Packer truck Incinerator

One of the primary objectives of the test program was to obtain data on bacterial levels at several plants so that a comparison of those levels could be made, in an attempt to determine if operations at the RDF plant represent any more of a hazard than those at other waste handling operations. For the most part, test results did show higher bacterial levels at the RDF plant for both the in-plant samples and the downwind property line samples. However, the results were not as clear cut as that statement would indicate because at the same time the upwind bacteria levels at the RDF plant were higher than those at the other plants. Downwind samples at the RDF plant may have been affected by operations at the incinerator because they are adjacent. These results might better be interpreted by comparison with appropriate standards, but no such standards exist.

The literature search provided limited information for interpreting the test results. Several researchers reported rapid die-off of aerosolized bacteria (and virus). For E. coli, it was found after a few seconds that only 10% remained viable but the loss of viability for those in larger particles was much less than in smaller particles (see Appendix I).

Reported concentrations of bacteria colonies in air cover a very large range, from 200/m^3 in a laboratory up to 700,000/m^3 at a sewage treatment plant. Airborne concentrations in country air, offices, streets, and factories were generally reported to be in the range of 2,000 to 4,000/m^3.

No information was found that would identify concentrations of total bacteria, or specific types of bacteria, which could be considered hazardous, primarily because dose/response relationships depend on the susceptibility of the receptor and many other factors.

Apparently, very few epidemiological studies have been carried out relative to airborne bacteria. One study by Cimino (8) found that the incidence of acute respiratory conditions for New York Sanitation Department workers did not exceed that of the general population. The inference from this was that there is no discernible health risk for aerosolized microorganisms. It could be argued, however, that such workers may develop a higher level of resistance to such aerosols than would the normal populace.

There does not appear to be any firm basis for judging the "potential hazard" of a given bacterial level. Therefore, it is almost impossible to make any such judgments about the data obtained in this program. The only statement that can justifiably be made is that if the levels measured at the RDF plant are higher than at other related facilities, this is probably not desirable and efforts should be made to control emissions from such operations (e.g., use of dust collection systems and fabric filters, and prevention of spillage).

Virus Emissions

Both bacteria and virus were included in the analysis program with emphasis on the determination of relative levels of each in the Hi-Vol samples taken at the property line and in-plant locations. In addition, virus analyses were to be carried out on the backup impingers used as part of the Andersen agar plate impactor samples taken at the upwind and downwind property line locations on one test day at each plant. Virus analyses were also to be performed on air classifier discharge samples, and mobile filter inlet/outlet samples taken during the week of testing at the RDF plant.

All of the samples analyzed were negative for the presence of animal viruses. Not all of the Hi-Vol and Andersen samples were analyzed for virus, but those which were analyzed included every specified location on at least one test day at each plant (i.e., at least five samples at each plant).

The initial testing at St. Louis (1) did not include any tests to determine virus (or bacteria) levels at in-plant or property line locations so no information was available for comparison. The initial tests did include virus tests at a suburban location but these were also negative.

Initial tests on samples of the particulate emitted from the air classifier discharge did show the presence of plaques (see Table 13) but in the latest series of tests, neither the air classifier samples nor the mobile filter samples which were analyzed showed the presence of viral plaques. The air classifier exhaust samples were probably the most likely to contain viruses. Since only three air classifier samples and three mobile filter inlet impinger samples were taken, negative results would not necessarily mean that viruses were not present. There does appear to be a discrepancy in the results between the present and previous virus tests on the material discharged from the air classifier system. However, there is some doubt about the previous results because further analyses were not carried out to identify the plaques as viral. Also, Peterson reported average virus concentrations in MSW of only 0.32 pfu/g. (9)

Using Peterson's (9) value of 0.32 pfu/g in MSW, and assuming that MSW particles suspended in ambient air might be on the order of 1,000 $\mu g/m^3$, it can be calculated that expected viral concentrations in the air might be 0.00032 pfu/m^3. Such levels are far below the minimum detectability of analysis procedures like those used in this program (0.4 pfu/m^3).* The analysis procedure and detection limits are further complicated by the fact that the weight of particulate matter collected on ambient Hi-Vol filters is normally quite small.

Because no viruses were being found in the samples within the detection limit of the laboratory procedures,* a quality control check was performed on the assay procedure using an attenuated poliovirus Type 1 culture. The control check showed that the laboratory assay procedures could detect virus if present in the sample concentrates. This verified the fact that no animal virus was present in the samples delivered to the laboratory. Since all samples tested negative for the presence of animal viruses, no Level 2 analyses were conducted.

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* Minimum detectability would theoretically be 10 pfu/ml (plaque forming units) of concentrated sample from which an aliquot was taken to perform the analysis. Total volume of concentrated sample was about 4 ml. This volume resulted from processing filters through which at least 100 m^3 of air had been passed. On this basis, minimum detectability would have been 0.4 pfu/m^3.

TABLE 13a. SUMMARY OF 1975 TEST DATA FOR BACTERIA AND VIRUS

						Bacteria concentrations			Plaque concentrations			
									Tests in LLC-MK$_2$ cells		Tests in KB cells	
Test No. and date	Raw refuse processing rate (Mg/hr)	Air flow (dNm^3/s)	Mass emissions g/m^3	Mass emissions kg/hr	Emission factor (kg/Mg)	Bacteria counts/gram[a] (counts/dNm^3)	Fecal coliform MPN/gram[b] (MPN/dNm^3)	Salmonella present (pos.) absent (neg.) and group	pfu/g	pfu/m^3	pfu/g	pfu/m^3
a. ADS cyclone												
1 (June 30, 1975)	18.1	13.64	0.25	11.9	0.66	27,000 (6,700)	2,100 (530)	Neg.	?[d]	?[d]	218	6
2 (July 1, 1975)	29.8	13.40	0.69	33.5	1.11	370,000,000 (256,000,000)	29,000 (20,000)	Pos. E 1	≥ 24,700	≥ 17,410	> 24,700	17,410
3 (July 1, 1975)	29.8	13.40	1.24	14.9	1.99	260,000,000 (318,000,000)	> 110,000 (> 134,000)	Pos. E 2	685-68,500	872-87,000	?[d]	?[d]
b. HM cyclone[c]												
1 (July 1, 1975)	29.8	0.78	1.17	3.3	0.11	730,000,000 (848,000,000)	2,900 (3,390)	Pos. C 1	?[d]	?[d]	7.35	9
2 (July 2, 1975)	25.7	0.78	1.10	3.1	0.12	160,000,000 (177,000,000)	43,000 (45,900)	Neg.	~ 171,232	~ 193,524	?[d]	?[d]
3 (July 2, 1975)	25.7	0.78	1.40	3.9	0.15	130,000,000 (180,000,000)	9,300 (13,100)	Neg.	~ 100	~ 145	?[d]	?[d]

---

[a] Total plate count per gram of particulate matter or per cubic meter of air emitted.

[b] Most probable number (MPN).

[c] Particulate concentration and emissions from hammermill (HM) were much higher than in previous tests. Reason for this is not known. However, cyclone had plugged up and had been washed out on day before tests.

[d] Results not definitive.

TABLE 13b. SUMMARY OF 1975 TEST DATA FOR BACTERIA AND VIRUS
(Emissions in storage bin)

Test No. and date	Gas sampled at 1.7 m^3/min rate (m^3)	Particulate collected (g)	Bacteria concentration		
			Bacteria counts/gram (counts/m^3)b/	Fecal coliform MPN/gram (MPN/m^3)b/	Salmonella present (pos.) absent (neg.) and group
1 (June 30, 1975)	306	6.01	248,000,000 (4,873,000)	1,400 (28)	Neg.
2 (July 1, 1975)	296	8.71	600,000,000 (17,657,000)	29,000 (862)	Neg.
3 (July 2, 1975)	311	1.08	145,000,000 (494,000)	512,000 (1,783)	Pos. O
4 (July 3, 1975)	442	52.53a/	213,000,000 (25,073,000)	1,600 (191)	Neg.

a/ Higher weight collected, probably due to fact that storage bin exhaust fan was on and distributing conveyor was on, which was not the case in Tests 1 through 3.

b/ Calculated value: $\left(\frac{\text{counts}}{\text{gram}}\right) \times \left(\frac{\text{grams of particulate}}{m^3 \text{ of gas sampled}}\right)$

TABLE 13c. SUMMARY OF 1975 TEST DATA FOR BACTERIA AND VIRUS
(Tests on ambient air, 25 km west of plant)

Test No. and date	Gas sampled (m^3)	Tare weight of filter[a] (g)	Bacteria concentration: Bacteria (counts/m^3)	Bacteria concentration: Fecal coliform (MPN/m^3)	Bacteria concentration: Salmonella present (pos.) absent (neg.) and group	Enterovirus concentration: Plaques per 1/2 filter pad	Enterovirus concentration: pfu/m^3	Bacteriophage for *E. coli*: Phage per 1/2 filter pad	Bacteriophage for *E. coli*: Phage/m^3
1 (June 30, 1975)	821	3.42	(473)	(< 0.141)	Neg.	0	< 0.0198	0	< 0.0035
2 (July 1, 1975)	886	3.50	(17)	(< 0.141)	Neg.	0	< 0.0184	0	< 0.0035
3 (July 2, 1975)	1,017	3.51	(28)	(< 0.141)	Neg.	0	< 0.0156	0	< 0.0035
4 (July 3, 1975)	643	3.52	(247)	(< 0.212)	Neg.	0	< 0.0247	0	< 0.0035
			Bacteriological contamination level assuming that 850 m^3 of sterile air had passed through blank filter[b]						
Blank filters									
a	None	3.50	7		Neg.	0		Not run	
b	None	3.31	254		Neg.	0		Not run	
c	None	3.48	< 0.035		Neg.				
d	None	3.56	0.035		Neg.				
e	None	3.53	< 0.035		Neg.				

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[a] Final weight of filter not determined because purpose of test was to determine biological contaminant concentrations on the basis of quantity of air sampled (m^3).

[b] Assumption made in order to compare blanks with actual samples.

While existence of virus at the field sampling locations could not be confirmed, some viruses could have been lost on the Hi-Vol filters as a result of physical and chemical effects on the filter surface. Examples of such effects are desiccation, oxidation, and complexation with dust material of unknown composition. Any of these items could potentially result in irreversible inactivation of the receptor sites on the protein capsid of the virus. Also, osmotic shock could result from a buildup of various salts on the filter from the collected dust.

All of the above could eventually result in devitalization of virus which could not then be detected in the laboratory.

During the performance of laboratory procedures it was noted that the Hi-Vol filter paper had a high pH which is detrimental to viability of virus life. This high pH could have inactivated many viruses. It was possible that during manufacture, the filters could have been cleaned with some hydroxide, resulting in the high pH. However, the more likely explanation of the negative virus results was that they were not present or were below the detection limits of the laboratory procedures. That is, the quantity of particulate matter collected on the Hi-Vol filters was small ($\ll$ 1 g) and as mentioned previously, reported values for MSW itself were only on the order of 0.32 pfu/g. Also, it was noted in the literature search (Appendix I) that experiments with liquid aerosols of high-titre virus suspensions have shown that mortality of the virus was very high during the first 2 min in aerial suspension. This may be an alternative explanation of why all the results obtained in this test program were negative.

TRACE METALS

A portion of the sampling program involved use of part of the Hi-Vol filters for trace element analysis. Those filters (samples) which were analyzed were the upwind and downwind location at each of the five plants plus two downtown samples and the three air classifier discharge samples.

A description of the analyses procedures for the trace elements in these samples is given in Appendix F. Complete results of those analyses are included in Appendix F. These results have been used to calculate trace element concentrations per unit volume of air sampled, and summarized in Table 14. Table 15 shows the trace element concentrations in the particulate matter emitted from the air classifier system and the concentration in terms of volume of air discharged.

Examination of the air classifier discharge results in Table 15 shows that Pb and Zn have, by far, the highest concentration. However, all of the trace elements analyzed, including Pb and Zn, were below their respective TLVs.

TABLE 14. TRACE ELEMENT CONCENTRATIONS FOR HI-VOL AMBIENT AIR SAMPLES

Sample No.	Location	Date	Element Concentrations (µg/m³) Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Se	Zn
	Incinerator											
049	Upwind	11/3/76	b/	< 0.007	0.00036	0.0025	< 0.05	0.12	0.93	b/	b/	0.42
051	Downwind	11/3/76	b/	< 0.007	0.00018	0.003	< 0.05	0.10	2.50	b/	b/	0.32
053	Downtown	11/3/76	b/	< 0.008	0.00020	0.002	< 0.05	0.05	0.97	b/	b/	0.13
	RDF plant											
082	Upwind	11/10/76	b/	< 0.007	0.00017	0.002	< 0.05	0.44	0.69	b/	b/	0.30
084	Downwind	11/10/76	b/	0.015	0.00056	0.007	0.17	0.39	2.25	b/	b/	1.96
089	Downtown	11/10/76	b/	< 0.007	<0.00010	0.0005	< 0.05	0.10	0.83	b/	b/	0.07
	WWTP[a/]											
115	Upwind	11/16/76	b/	< 0.008	0.00006	0.0026	< 0.05	0.13	0.64	b/	b/	0.12
117	Downwind	11/16/76	b/	< 0.007	0.00013	0.003	< 0.05	0.22	0.98	b/	b/	0.13
	Waste Transfer											
110	Upwind	11/24/76	b/	< 0.007	0.00014	0.002	0.17	0.13	< 0.5	b/	b/	0.24
202	Downwind	11/24/76	b/	0.009	0.00022	0.002	0.14	0.18	1.5	b/	b/	0.20
	Landfill											
216	Upwind	11/30/76	b/	< 0.007	<0.00007	0.0015	< 0.05	0.07	1.18	b/	b/	0.06
218	Downwind	11/30/76	b/	< 0.007	0.00020	0.0005	< 0.05	0.05	0.59	b/	b/	0.09
	TLV/100		0.50	0.50	0.02	0.50	1.0	2.0	1.5	0.50	2.0	5.0

a/ Wastewater treatment plant.

b/ All values below detection limits (Sb-0.02, As-0.007, Hg-0.002, Se-0.04).

TABLE 15. TRACE ELEMENT RESULTS FOR AIR CLASSIFIER DISCHARGE SAMPLES

Element sample	Date	Trace element concentration (µg/g)										
		Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Se	Zn	Ba
Air classifier 1-3	11/9/76	< 5.0	22.0	0.22	19.0	81.0	74.0	430.0	0.93	30.0	680.0	130.0
Air classifier 2-3	11/10/76	4.2	9.1	0.18	7.0	78.0	60.0	370.0	0.35	28.0	520.0	94.0
Air classifier 3-3	11/11/76	7.7	5.7	0.23	4.6	97.0	100.0	400.0	<0.40	25.0	740.0	130.0
		Trace element concentration (µg/m³)										
Air classifier 1-3	11/9/76	1.3	5.8	0.058	5.0	21.7	19.0	113.0	0.24	7.9	178.0	34.0
Air classifier 2-3	11/10/76	1.5	3.3	0.065	2.5	28.0	21.5	133.0	0.13	10.0	187.0	33.7
Air classifier 3-3	11/11/76	2.1	1.5	0.062	1.2	26.0	27.0	107.0	0.11	6.7	198.0	34.8
	TLV	50.0	50.0	2.0	50.0	100.0	200.0	150.0	50.0	200.0	5,000.0	500.0

Elemental concentrations at the property lines of the plants (upwind and downwind) and downtown, as given in Table 14, allow four main observations:

1. There was a significant increase in the downwind concentration at the RDF plant and the waste transfer station.

2. There was a significant increase in the downwind Cr concentration at the RDF plant and both the upwind and downwind Cr concentrations were much higher at the waste transfer station than at all other plants (except the RDF plant).

3. There was a significant increase in the downwind Zn concentration at the RDF plant.

4. The downwind Pb concentration was higher than the upwind at all plants except the landfill.

Since there are no ambient air standards for most of the trace elements, it is difficult to assess the above results in terms of potential hazards. However, if one assumes that such results can be compared with 1/100 of TLV, then an initial comparison is possible. On this basis, the data in Table 14 show that all of the measured trace element concentrations were considerably below 1/100 of the respective TLVs, except for Pb.

Concentrations of Pb were close to 1/100 of TLV even in the upwind and downtown samples. But, the downwind Pb concentrations exceeded 1/100 of TLV at the incinerator and RDF plant, and were just equal to 1/100 of TLV at the waste transfer station. It appears that operation at such refuse handling facilities may contribute significantly to the burden of Pb in the ambient air which places more emphasis on the Pb concentration in emissions from the uncontrolled air classifier system. Although Pb and other trace elements were not measured in the outlet from the mobile fabric filter, the high total particulate efficiency would be expected to also reduce the associated Pb emissions.

AIR CLASSIFIER PARTICULATE EMISSION AND MOBILE FABRIC FILTER EFFICIENCY

Emission of particulate from the air classifier system was measured with Hi-Vol stack sampling equipment. Results showed particulate concentrations of 0.26, 0.36, and 0.27 g/dNm^3. These were in close agreement with the previous MRI (1) tests and the tests conducted by Monsanto (Appendix E) on the inlet of the EPA mobile filter.

Monsanto operated the EPA mobile filter during the 3 days of testing at the RDF plant in conjunction with the bacteria and virus tests by MRI. This mobile filter was connected to a sidestream drawoff from the air classifier exhaust, at a flow rate of 0.05 dNm^3/sec.

A description of the mobile filter and the particulate test results is contained in Appendix E. The filter test results showed an inlet particulate concentration of 0.300 g/nm^3 and an outlet concentration of 0.000154 g/nm^3, yielding a total mass efficiency of 99.95%. This efficiency is about what would be expected for a baghouse in this service, indicating that such devices are very effective in reducing particulate emissions. Data presented earlier in this report showed that the bacteria removal efficiency of the mobile filter was 99.6% based on total bacteria count and at least 99.9% for specific types of bacteria (e.g., total coliform). There appears to be a good correlation between particulate removal efficiency and bacterial removal efficiency for this baghouse.

It was originally intended that samples taken at the air classifier would be analyzed for asbestos content as would the upwind, downwind, and downtown Hi-Vol samples, by our subcontractor, Illinois Institute of Technology Research Institute (IITRI). Unfortunately, the glass fiber filter papers used in the Hi-Vol for all analyses (bacteria and trace metals) were not suitable for asbestos analyses. We had originally understood that this filter paper would be suitable but later found that asbestos analyses require the use of 0.8 μm pore size Nuclepore filter. Therefore, asbestos analyses could only be carried out on the air classifier exhaust where a large amount of sample is collected. From one standpoint, this is probably the most important sample because it represents a possible source of asbestos emissions.

The results reported by IITRI on the air classifier exhaust samples (Appendix D) showed that 15 out of 19 fibers were asbestos in one sample. In the other sample, 18% of the fibers were analyzed and all were determined to be asbestos so it was assumed that all fibers were asbestos. On a weight basis, it was calculated that the mass of asbestos fibers per mass of sample material was 1.6 and 0.46%, respectively.

Initially it appeared that the amount of asbestos being emitted from the air classifier could be significant. The IITRI data showed the highest concentration sample contained 15 fibers in 35.6 μg of particulate sample, but when coupled with the particulate concentration of 0.23 μg/cc of air, it is calculated that the air classifier was emitting 0.10 fibers of asbestos per cubic centimeter. This emission quantity is considerably below the TLV (10) of 5 fibers/cc (for fibers greater than 5 μm in length). Many of the asbestos fibers identified by IITRI in their analysis were less than 5 μm in length so it is uncertain whether comparison with the TLV is entirely valid. But, investigations by the National Academy of Sciences (11) indicate that it was not possible to determine whether the fibrogenicity of asbestos dust is mostly confined to fibers longer than 5 μm. With this uncertainty, the comparison of the test data with the TLV results in the conclusion that emission of asbestos from the air classifier system does not represent a potential hazard.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The primary purpose of this program was investigative; i.e., to obtain basic data on levels of bacteria and virus in and around waste handling facilities and to perform sampling and analysis for certain other contaminants. From the experience gained in acquisition of data and interpretation of results, certain conclusions and recommendations can be presented. However, these conclusions are based on a test program consisting basically of only three test days at each plant, taking seven 6-hr Hi-Vol filter samples each day and five short-term Andersen samples.

CONCLUSIONS

- Airborne bacterial levels, both in-plant and at the property line, were generally higher for the RDF plant than for the other types of waste facilities that were tested.
- There is insufficient information, data, or relevant standards to determine the levels of microbiological contaminants that might be considered "hazardous."
- Asbestos emissions from the RDF plant tested were below the TLV.
- Property line concentrations for most airborne particulate containing trace metals were below an arbitrary level of 1/100 of the TLV.
- Property line concentrations for Pb, contained in particulate collected, were near or exceeded 1/100 of the TLV at the RDF plant, incinerator and waste transfer station.
- A fabric filter system applied to the primary source of dust emissions (air classifier) at the refuse processing plant can significantly reduce particulate and bacteria concentrations.

RECOMMENDATIONS

- Waste handling facilities which may emit airborne particulates should be designed and equipped to minimize emissions. Suitable control systems could include process modifications, operating procedures, and dust collection and control equipment.

- There is a need for development of standarized sampling and analysis methodology for airborne microorganisms and other pollutants (e.g., trace metal vapors).

- The EPA and/or other appropriate agencies should promote further research to investigate possible environmental effects of airborne microorganisms associated with waste handling facilities.

- Since only a few days of sampling were conducted at each waste handling facility, it is recommended that additional research programs be conducted at waste handling facilities, over longer time periods (e.g., months, years) to better characterize emissions and evaluate any possible environmental effects.

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APPENDIX A

DETAILED DESCRIPTION OF TEST PLAN

A large part of the sampling plan involved Hi-Vol and Andersen agar plate impactor sampling for 3 days at the property line and at in-plant locations at five different plants. The plants sampled were:

1. Incinerator;
2. Refuse processing plant;
3. Sewage treatment plant;
4. Refuse transfer station; and
5. Landfill.

Except for some special additional tests, mainly at the RDF plant, the sampling at each plant was as follows:

1. Hi-Vol samplers at property line (one upwind, three downwind).
2. Hi-Vol with precyclone samplers in-plant (three locations).
3. Andersen agar plate impactors with backup impinger at the property line (one upwind, one downwind).
4. Andersen agar plate impactors with backup impinger at three in-plant locations.

A more complete listing of the sampling locations, with number and type of samplers is given in Table A-1. Table A-2 shows the analyses that were performed on each Hi-Vol impactor sample. The number of sampler and their analysis is also shown, in more detail, in Table A-3. Analyses referred to in these tables are identified in Table A-4. A summary of the sampling and analysis plan for each plant is given on individual sheets in Table A-5.

Copies of the field laboratory log sheets and sample labels that were utilized in the field sampling are shown in Tables A-6 to A-11.

TABLE A-1. SAMPLING LOCATIONS AND TYPES OF SAMPLERS

Plant	Operating conditions	Days of sampling	Sampling locations	Number and type of samplers
Incinerator	Operating (RDF plant not operating	3	Prop. Line	4 Hi-Vols, 2 Impactors
			Downtown St. Louis	1 Hi-Vol
			In-Plant:	
			Tipping Floor	1 Hi-Vol, 1 Impactor
			Scale Office	1 Hi-Vol, 1 Impactor
			Crane above charging floor	1 Hi-Vol, 1 Impactor
			Packer truck	2 Hi-Vol Samplers
RDF plant	Operating (Incinerator Operating)	3	Prop. Line	4 Hi-Vols, 2 Impactors
			Downtown St. Louis	1 Hi-Vol
			In-Plant:	
			Recvg. Bldg.	1 Hi-Vol, 1 Impactor
			Control Rm.	1 Hi-Vol, 1 Impactor
			Packer Sta.	1 Hi-Vol, 1 Impactor
			Mobil filter	
			Inlet	2 Impingers in Series
			Outlet	1 Impinger
			ADS Exhaust	1 Hi-Vol Stack Sampler
			Refuse Samples	3 Grab Samples
Sewage treatment plant	Operating	3	Prop. Line	4 Hi-Vols, 2 Impactors
			In-Plant:	
			Near Primary Basins	1 Hi-Vol, 1 Impactor
			Near Aeration Basins	1 Hi-Vol, 1 Impactor
			Operator Sta. in Building Between Primary and Aeration Basins	1 Hi-Vol, 1 Impactor
Transfer station (Kansas City)	Operating	3	Prop. Line	4 Hi-Vols, 2 Impactors
			In-Plant:	
			Recvg. Area	2 Hi-Vols, 2 Impactors
			Packing Area	1 Hi-Vol, 1 Impactor
Landfill (Kansas City)	Operating	3	Prop. Line	4 Hi-Vols, 2 Impactors
			In-Plant:	
			Working Face	2 Hi-Vols, 2 Impactors
			Near Scale	1 Hi-Vol, 1 Impactor

TABLE A-2. ANALYSES TO BE PERFORMED ON HI-VOL AND ANDERSEN SAMPLES TAKEN DAILY AT EACH PLANT (ANALYSES TO BE PERFORMED EACH DAY'S SAMPLES AT EACH PLANT, EXCEPT AS NOTED)

A. Hi-Vols at property line (4)[a]

1 upwind and 1 downwind

Bacteria and Virus--Level 2	
Microbial Morphology	only on upwind and downwind samples from one test day
Trace Metals	
Physical/chemical morphology	

2 downwind

Bacteria and Virus--Level 1

B. Hi-Vols with precyclone in-plant (3 in-plant locations)
Bacteria and Virus--Level 2

C. Andersen Impactor with backup impinger at Property Line (1 upwind, 1 downwind)
Total bacteria count on each stage; save impinger solution by freezing.
Microbial morphology on each stage, and virus (level 1) in impinger, for samples from one test day

D. Andersen Impactor with backup impinger, in-plant (3 in-plant locations)
Total bacteria count on each stage. Save impinger solution by freezing for later analysis of virus (Level 1).

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[a] Hi-Vol samples were also taken at downtown site and underwent the same analysis as upwind/downwind Hi-Vols at property line (see A above). Downtown location was sampled only during week of tests at RDF plant and week of tests at incinerator.

TABLE A-3. DAILY SAMPLES AT EACH PLANT (3 TEST DAYS) HI-VOLS, AND ANDERSENS WITH BACKUP IMPINGERS, IMPINGERS, AND REFUSE SAMPLES

I. Hi-Vols

A. Hi-Vols at property line (sample for 6 hr)

HiV 1 upwind → Filt. Cut in 1/4's if required. Put in sterile container

- $\xrightarrow{ice}$ to MRI for B&V (Level 2)
- $\xrightarrow{ice}$ to MRI for microbial morphology
- → to MRI for trace metals (include 1/4 blank filter)
- → to MRI for transfer to IITRI

Analysis to be done only on samples from one test day at each plant

HiV 2 downwind → Filt. Cut in 1/4 if required. Put in sterile container

- $\xrightarrow{ice}$
- $\xrightarrow{ice}$
- →
- →

Same as above

HiV 3 other downwind → Filt. Put in sterile container $\xrightarrow{ice}$ to MRI for B&V (Level 1)

HiV 4 other downwind → Filt. Put in sterile container $\xrightarrow{ice}$ to MRI for B&V (Level 1)

B. Hi-Vol w precyclone in-plant (sample for 6 hr)

HiV 5 In-Plant Loc. 1 Filt. Put in sterile container $\xrightarrow{ice}$ to MRI for B&V (Level 2)

(continued)

TABLE A-3 (continued)

HiV 6 → Filt $\xrightarrow{\text{ice}}$ to MRI for B&V (Level 2)
In-Plant Put in sterile
Loc. 2 container

HiV 7 → Filt $\xrightarrow{\text{ice}}$ to MRI for B&V (Level 2)
In-Plant Put in sterile
Loc. 3 container

C. Hi-Vol downtown (sample for 6 hr) - 2 test weeks only

HiV 8 → Filt → $\xrightarrow{\text{ice}}$ $\xrightarrow{\text{ice}}$ → → } Same as HiV 1 (above)
downtown Cut in 1/4.
Put in sterile
container

(continued)

TABLE A-3 (continued)

II. Andersen Agar Plate Impactors with Backup Impinger

D. Andersen Agar Plate Impactor with Backup Impinger - Property Line (1 upwind, 1 downwind) (sample for 10 min)

Andersen 1 Upwind at HiV 1	——>	Cover and seal each plate. Place in watertight container and store in ice chest. Put impinger solution in sterile bottle and store in ice chest.	$\xrightarrow{\text{ice}}$	To MRI for total bacteria count on each stage. Save impinger solution. Microbial morphology on each stage, and virus (Level 1) in impinger, for samples from one test day.
Andersen 2 Downwind at HiV 2	——>	Same as above.	$\xrightarrow{\text{ice}}$	Same as above.

E. Andersen Agar Plate Impactor with Backup Impinger - In-Plant (three locations In-Plant) (sample for 30 sec)

Andersen 3 Loc. 1	——>	Cover and seal each plate. Place in watertight container and store in ice chest. Put impinger solution in sterile bottle and store in ice chest.	$\xrightarrow{\text{ice}}$	To MRI for total bacteria count on each stage. Save impinger solution by freezing for later analysis of virus (Level 1)
Andersen 4 Loc. 2	——>	Same as above.	$\xrightarrow{\text{ice}}$	Same as above.
Andersen 5 Loc. 3	——>	Same as above.	$\xrightarrow{\text{ice}}$	Same as above.

(continued)

TABLE A-3 (continued)

III. Additional Daily Samples for Week of Tests at RDF Plant

F. Air Classifier Stack, Hi-Vol Filter (sample for 1/2 to 1 hr)

Filter (preweighed) ——> Weigh, Cut in 1/4s. Place in sterile bottles.
- —ice—> to MRI for B&V (Level 2)
- —ice—> to MRI for microbial morphology
- ——> to MRI for trace metals (include 1/4 blank filter)
- ——> to MRI for transfer to IITRI for physio/chem morphology

G. Mobile Filter Test, Impingers (~ 0.47 liters/sec sampling rate for 6 hr)

Inlet:

Impinger 1 (mod. G.S. impinger) + Impinger 2 (G.S. impinger) ——> Combine in sterile bottle —ice—> To MRI for bacteria and virus (Level 2) and microbial morphology

Outlet:

Impinger 3 (G.S. impinger) ——> Same as above. —ice—> Same as above.

H. Refuse samples (HM discharge)

HM discharge 3 samples per day —ice—> Place in sterile bottles. —ice—> To MRI for bacteria and virus (Level 2)

(continued)

TABLE A-3 (continued)

IV. Additional Daily Samples for Week of Tests at Incinerator Plant

I. Packer Truck Hi Vol with Precyclone (2 - one on each side at back of packer truck)

Filter 2 samples per day	——>	Place in sterile container in ice chest	ice ——>	To MRI for bacteria and virus (Level 1).

TABLE A-4. IDENTIFICATION OF ANALYSIS SPECTRUM

A. Bacteria and Virus[a]

Level 1 Tests[a]	Level 2 Tests[a]
Bacteria	
Total aerobic plate count	Relative changes in predominant morphological groups
Salmonellae (MPN)	(1) Determine serotypes (2) Antibiotic sensitivity
Staphylococcus aureus (Direct plate count)	(1) Coagulase production (2) Antibiotic sensitivity (3) Bacteriophage typing
Total coliform (MPN)	No additional assays
Fecal coliform (MPN)	Enteropathogenic serotype of *E. coli*
Fecal Streptococci (Direct plate count)	
Klebsiella sp. (est. from selective media)	Serotype for pathologically significant groups
Virus	
Estimations of population sizes of adenoviruses and enteroviruses. To be done using two cell lines and determining pfu/m^3.	Serological identification of the relative populations of adenoviruses (human type), polioviruses (vaccine and wild types), coxsackie viruses (A and B), and echoviruses.

B. Microbial Morphology

(1) Isolation of individual bacterial types
(2) Determination of their morphologic characteristics (gram +, or gram -, rods or cocci, etc.), and
(3) Cultivation on agar slants for future reference and identification.

(continued)

TABLE A-4 (continued)

C. Physio/Chemical Morphology

Electron microscopic examination of samples by IITRI with particular attention to fibrous particles and a check as to whether they may be asbestos.

D. Trace Metals

As, Sb, Ba, Be, Cd, Cr, Cu, Pb, Hg, Se, Ag, Ti, V, Zn

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a/ Level 2 tests for bacteria and virus include all analysis shown in Level 1 column plus additional analysis shown in the Level 2 column.

TABLE A-5. SUMMARY OF SAMPLING AND ANALYSIS PLAN[a/]

Plant	Location of sampler	Type of sampler	Date 1976	Sample period	Analyses performed							
					B-L1	B-L2	TBC	V-L1	V-L2	PCM	TM	MM
Incin	Upwind	Hi-Vol	11-2,3,4	6 hr	X	X	1	X	X	1		1
Incin	Upwind	Andersen	11-2,3,4	10 min			X	1-BUI				1
Incin	Dw prim	Hi-Vol	11-2,3,4	6 hr	X	X		X	X	1	1	1
Incin	Dw prim	Andersen	11-2,3,4	10 min			X	1-BUI				1
Incin	Dw 2nd	Hi-Vol	11-2,3,4	6 hr	X			X				
Incin	Dw 2nd	Hi-Vol	11-2,3,4	6 hr	X			X				
Incin	Tip flr	Hi-Vol	11-2,3,4	6 hr	X	X		X	X			
Incin	Tip flr	Andersen	11-2,3,4	30 sec			X	BUI				
Incin	Scale off	Hi-Vol	11-2,3,4	6 hr	X	X		X	X			
Incin	Scale off	Andersen	11-2,3,4	30 sec			X	BUI				
Incin	Crane	Hi-Vol	11-2,3,4	6 hr	X	X		X	X			
Incin	Crane	Andersen	11-2,3,4	30 sec			X	BUI				
Incin	Downtown	Hi-Vol	11-2,3,4	6 hr	X	X		X	X	1	1	1
Incin	Packer trk	(2) Hi Vol	11-2,3,4	Approx. 2 hr	X	X		X	X	1	1	1

(continued)

TABLE A-5 (continued)

Plant	Location of sampler	Type of sampler	Date 1976	Sample period	Analyses performed B-L1	B-L2	TBC	V-L1	V-L2	PCM	TM	MM
Process	Upwind	Hi-Vol	11-9,10,11	6 hr	X	X		X	X	1	1	1
Process	Upwind	Andersen	11-9,10,11	10 min			X	1-BUI				1
Process	Dw prim	Hi-Vol	11-9,10,11	6 hr	X	X		X	X	1	1	1
Process	Dw prim	Andersen	11-9,10,11	10 min			X	1-BUI				1
Process	Dw 2nd	Hi-Vol	11-9,10,11	6 hr	X			X				
Process	Dw 2nd	Hi-Vol	11-9,10,11	6 hr	X			X				
Process	Tip flr	Hi-Vol	11-9,10,11	6 hr	X	X		X	X			
Process	Tip flr	Andersen	11-9,10,11	30 sec			X	BUI				
Process	Control room	Hi-Vol	11-9,10,11	6 hr	X	X		X	X			
Process	Control room	Andersen	11-9,10,11	30 sec			X	BUI				
Process	Pack sta	Hi-Vol	11-9,10,11	6 hr	X	X		X	X			
Process	Pack sta	Andersen	11-9,10,11	30 sec			X	BUI				
Process	Ads exn	Hi-Vol	11-9,10,11	1/2 to 1 hr	X	X		X	X	X	X	X
Process	Downtown	Hi-Vol	11-9,10,11	6 hr	X	X		X	X	1	1	1
Process	H.M. disc	(3) Grab	11-9,10,11	--	X	X		X	X			
Process	Mob flt in	(2) Imping	11-9,10,11	6 hr	X	X		X	X			X
Process	Mob flt out	(1) Imping	11-9,10,11	6 hr	X	X		X	X			X
Sewage	Upwind	Hi-Vol	11-16,17,18	6 hr	X	X		X	X	1	1	1
Sewage	Upwind	Andersen	11-16,17,18	10 min			X	1-BUI				1
Sewage	Dw prim	Hi-Vol	11-16,17,18	6 hr	X	X		X	X	1	1	1
Sewage	Dw prim	Andersen	11-16,17,18	10 min			X	1-BUI				1
Sewage	Dw 2nd	Hi-Vol	11-16,17,18	6 hr	X			X				

(continued)

TABLE A-5 (continued)

Plant	Location of sampler	Type of sampler	Date 1976	Sample period	Analyses performed B-L1	B-L2	TBC	V-L1	V-L2	PCM	TM	MM
Sewage	Dw 2nd	Hi-Vol	11-16,17,18	6 hr	X			X				
Sewage	Prim basin	Hi-Vol	11-16,17,18	6 hr	X	X		X				
Sewage	Prim basin	Andersen	11-16,17,18	30 sec			X	BUI				
Sewage	Aeration bas	Hi-Vol	11-16,17,18	6 hr	X	X		X				
Sewage	Aeration bas	Andersen	11-16,17,18	30 sec			X	BUI				
Sewage	Press-room	Hi-Vol	11-16,17,18	6 hr	X	X		X				
Sewage	Press-room	Andersen	11-16,17,18	30 sec			X	BUI				
Sewage	Pressrm bsmt	Hi-Vol	11-16,17,18	6 hr	X	X		X				
Sewage	Pressrm bsmt	Andersen	11-16,17,18	30 sec			X	BUI				
Waste trans	Upwind	Hi-Vol	11-22,23,24	6 hr	X	X		X	X	1	1	1
Waste trans	Upwind	Andersen	11-22,23,24	10 min			X	1-BUI				1
Waste trans	Dw prim	Hi-Vol	11-22,23,24	6 hr	X	X		X	X	1	1	1
Waste trans	Dw prim	Andersen	11-22,23,24	10 min			X	1-BUI				1
Waste trans	Dw 2nd	Hi-Vol	11-22,23,24	6 hr	X			X				
Waste trans	Dw 2nd	Hi-Vol	11-22,23,24	6 hr	X			X				
Waste trans	Tip flr north	Hi-Vol	11-22,23,24	6 hr	X	X		X	X			
Waste trans	Tip flr north	Andersen	11-22,23,24	30 sec			X	BUI				

(continued)

TABLE A-5 (continued)

Plant	Location of sampler	Type of sampler	Date 1976	Sample period	B-L1	B-L2	TBC	V-L1	V-L2	PCM	TM	MM
Waste trans	Tip flr east	Hi-Vol	11-22,23,24	6 hr	X	X		X	X			
Waste trans	Tip flr east	Hi-Vol	11-24	2 hr	X	X		X	X			
Waste trans	Tip flr east	Andersen	11-22,23,24	30 sec			X	BUI				
Waste trans	Pack ramp	Hi-Vol	11-22,23,24	6 hr	X	X		X	X			
Waste trans	Pack ramp	Andersen	11-22,23,24	30 sec			X	BUI				
Landfill	Upwind	Hi-Vol	11-29,30 & 12-1	6 hr	X	X		X	X	1	1	1
Landfill	Upwind	Andersen	11-29,30 & 12-1	10 min			X	1-BUI				1
Landfill	Dw prim	Hi-Vol	11-29,30 & 12-1	6 hr	X	X		X	X	1	1	1
Landfill	Dw prim	Andersen	11-29,3 & 12-1	10 min			X	1-BUI				1
Landfill	Dw 2nd	Hi-Vol	11-29,3 & 12-1	6 hr	X			X				
Landfill	Dw 2nd	Hi-Vol	11-29,30 & 12-1	6 hr	X			X				
Landfill	Wrk face east	Hi-Vol	11-29,30 & 12-1	6 hr	X	X		X	X			
Landfill	Wrk face east	Andersen	11-29,30 & 12-1	30 sec			X	BUI				
Landfill	Wrk face west	Hi-Vol	11-29,30 & 12-1	6 hr	X	X		X	X			
Landfill	Wrk face west	Andersen	11-29,30 & 12-1	30 sec			X	BUI				
Landfill	Scale	Hi-Vol	11-29,30 & 12-1	6 hr	X	X		X	X			
Landfill	Scale	Andersen	11-29,30 & 12-1	30 sec			X	BUI				

a/ B-L1 = Bacteria Level 1
B-L2 = Bacteria Level 2
V-L1 = Virus Level 1
V-L2 = Virus Level 2
PCM = Physio/Chemical Morphology
TM = Trace metals
MM = Microbial morphology
TBC = Total bacteria count
BUI = Backup impinger
X = Analysis to be performed on sample from each test day
1 = Analysis to be performed on sample from only one test day

TABLE A-6. FIELD LABORATORY LOG FOR HI-VOL SAMPLES

Date____________________
By____________________

Test Day No. 1 at Each Plant

	Property Line				Inplant			Downtown a/	Packer Truck b/		Blank
Sample No.											
Location No. Per Map or Name	(UW)	(DW)	(DW)	(DW)					Left	Right	
Analysis Req'd	L2	L2	L1	L1	L2	L2	L2	L2	L1	L1	L1
Hi Vol No./a/s											
Sampling Time (Start/Stop)											

Date____________________
By____________________

Test Day No. 2 at Each Plant

	Property Line																				
	Upwind				Downwind				Other Dwnwd	Other Dwnwd	Inplant			Downtown a/				Packer Truck b/		Blank	
Sample No.																					
Location No. Per Map or Name														Downtown 1/				Left	Right		
Filter Size	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	F	F	F	F	F	1/4	1/4	1/4	1/4	F	F	1/4	1/4
Analysis Req'd	L2	MM	TM	PCM	L2	MM	TM	PCM	L1	L1	L2	L2	L2	L2	MM	TM	PCM	L1	L1	L1	L1
Hi Vol No./a/s																					
Sampling Time (Start/Stop)																					

Date____________________
By____________________

Test Day No. 3 at Each Plant

	Property Line				Inplant			Downtown a/	Packer Truck b/		Blank
Sample No.											
Location No. Per Map or Name	(UW)	(DW)	(DW)	(DW)					Left	Right	
Analysis Req'd	L2	L2	L1	L1	L2	L2	L2	L2	L1	L1	L1
Hi Vol No./a/s											
Sampling Time (Start/Stop)											

a/ Downtown Hi-Vol will be operated only during week of tests at Incinerator and week at RDF plant.

b/ Packer Truck Hi-Vols (2) will be operated only during week of tests at Incinerator.

TABLE A-7. FIELD LABORATORY LOG FOR ANDERSEN IMPACTOR SAMPLES

Test Day No. 1 at Each Plant Date __________ By ________________

	Property Lines														Inplant																				
	Upwind							Downwind																											
Sample No.																																			
Stage No.	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Location No. or Name																																			
Analysis Req'd	TBC						S	TBC						S	TBC						S	TBC						S	TBC						S
Sampling Rate in ℓ/s																																			
Sampling Time																																			
Andersen No.																																			

Test Day No. 2 at Each Plant Date __________ By ________________

	Property Lines														Inplant																				
	Upwind							Downwind																											
Sample No.																																			
Stage No.	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Location No. or Name																																			
Analysis Req'd	TBC & MM						V (1)	TBC & MM						V (1)	TBC						S	TBC						S	TBC						S
Sampling Rate in ℓ/s																																			
Sampling Time																																			
Andersen No.																																			

Test Day No. 3 at Each Plant Date __________ By ________________

	Property Lines														Inplant																				
	Upwind							Downwind																											
Sample No.																																			
Stage No.	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Location No. or Name																																			
Analysis Req'd	TBC						S	TBC						S	TBC						S	TBC						S	TBC						S
Sampling Rate in ℓ/s																																			
Sampling Time																																			
Andersen No.																																			

TABLE A-8. FIELD LABORATORY LOG FOR RDF PLANT SAMPLES

Test Day No. 1 Date__________ By__________________

	Blank		ADS Exhaust				Mobile Filter		Refuse Sample		
Sample No.											
Location or Name			Filter & Catch				Inlet	Outlet	HM Discharge		
Type or Filter Size	1/4	1/4	1/4	1/4	1/4	1/4	Imp.	Imp.	×	×	×
Sampling Rate ℓ/s									×	×	×
Sampling Period (Times)			start			stop			×	×	×
Gross Weight or Volume	gms	gms				gms	ml	ml	gms	gms	gms
Analysis Req'd	L1	TM	L2	MM	TM	PCM	L2 & MM	L2 & MM	L2	L2	L2

Test Day No. 2 Date__________ By__________________

	Blank		ADS Exhaust				Mobile Filter		Refuse Sample		
Sample No.											
Location or Name			Filter & Catch				Inlet	Outlet	HM Discharge		
Type or Filter Size	1/4	1/4	1/4	1/4	1/4	1/4	Imp.	Imp.	×	×	×
Sampling Rate ℓ/s									×	×	×
Sampling Period (Times)			start			stop			×	×	×
Gross Weight or Volume	gms	gms				gms	ml	ml	gms	gms	gms
Analysis Req'd	L1	TM	L2	MM	TM	PCM	L2 & MM	L2 & MM	L2	L2	L2

Test Day No. 3 Date__________ By__________________

	Blank		ADS Exhaust				Mobile Filter		Refuse Sample		
Sample No.											
Location or Name			Filter & Catch				Inlet	Outlet	HM Discharge		
Type or Filter Size	1/4	1/4	1/4	1/4	1/4	1/4	Imp.	Imp.	×	×	×
Sampling Rate ℓ/s									×	×	×
Sampling Period (Times)			start			stop			×	×	×
Gross Weight or Volume	gms	gms				gms	ml	ml	gms	gms	gms
Analysis Req'd	L1	TM	L2	MM	TM	PCM	L2 & MM	L2 & MM	L2	L2	L2

TABLE A-9. LABEL FOR HI-VOL SAMPLES

Sample No. ____________________
Sample Date ____________________
Test Day No. ____________________(1, 2, or 3)
Hi-Vol No. _________/_________ liters/sec flow rate
Sampling Time ____________________
Location (per map) or Name ____________________
Filt Size ____________________ (1/4 or full)
Circle Analysis Required: L1, L2, MM, TM, PCM

TABLE A-10. LABEL FOR ANDERSEN IMPACTOR SAMPLES

Sample No. ____________________
Location (per map) or Name ____________________
Sample Date ____________________
Test Day No. ____________________ (1, 2 or 3)
Andersen No. __________, __________ liters/sec flow rate
Sampling Time ____________________
Stage No. ____________________ (1-7, stg 7 is impinger soln)
Circle Analysis Rqd: TBC, MM; Virus (L1), Save
(Impingers)

TABLE A-11. SAMPLE OF LABEL

Label for:

a. Air classifier exhaust
b. Air classifier filter-inlet or outlet impinger
c. HM discharge sample

Sample No. ____________________
Sample Name ____________________ (see above)
Sample Date ____________________
Test Day No. ____________________
Sampling Rate ____________________ liters/sec
Sampling Time __________/__________
start stop
Sample Type (circle one):
1/4 filter, impinger soln., HM discharge

Approx. Wt. or Vol of Sample ____________________ g or ml
(including filter paper)

Circle Analysis Req'd: L1, L2, MM, TM, PCM

APPENDIX B

FIELD TEST METHODOLOGY

The bacterial and viral sampling and analysis program included comparable testing at five related waste handling operations:

1. Incinerator plant;
2. St. Louis Refuse Processing Plant;
3. Wastewater treatment plant;
4. Waste transfer station; and
5. Sanitary landfill.

There was a basic standard test plan employed at all five facilities plus special tests at four of the facilities so conditions which were unique to each facility could also be analyzed.

This section of the report will include the following:

1. A description of the sampling equipment;
2. A synopsis of the pretest activities;
3. A list of the general order of daily events during the testing;
4. A map and description of each test facility;
5. The amount of refuse or waste processed each test day;
6. A review of each sample location at each test facility;
7. What test equipment was used;

8. Why each sampling location was selected; and

9. How the samples were handled.

SAMPLING EQUIPMENT

The major item of sampling equipment used for the tests was the Hi-Vol sampler. The upwind and downwind Hi-Vols were standard units and the in-plant Hi-Vols were equipped with precyclones. All of the Hi-Vols operated at a continuous sampling rate of 18.9 liters/sec for 6 hr and were equipped with a sterile fiberglass filter for a sample collection media.

The second most used sampler was the Andersen impactor with a backup impinger. All of the Andersen samples were taken at a sampling rate of 0.466 liters/sec and used agar plates for sample collection. The backup impinger used Hank's balanced salt solution for the collection media and was analyzed for virus only.

Impingers were used alone for special B and V sampling at the RDF plant on the mobile filter inlet and outlet. The sampling rate was 0.466 liters/sec and Hank's balanced salt solution was used for the collection media.

PRETEST ACTIVITIES

The test plan called for testing each facility on three consecutive days. On Monday of each test week for the incinerator, the RDF plant, and the sewage treatment plant, the schedule was as follows:

1. Check out the plant.

2. Determine the in-plant sample locations.

3. Locate the power supplies for the test equipment.

4. Determine the location of the meteorological station.

5. Obtain all additional equipment necessary to run the tests (electrical connectors, extension cords, extra generators, etc.).

6. Set up the test equipment and run preliminary tests to check out equipment, the sample handling procedure, and the shipment of samples to MRI.

For the waste transfer station and the landfill, Steps (1) through (5) were accomplished on Friday prior to the test week and Step (6) was eliminated as time was a factor and because the test facilities operated long enough each day to complete the test even if any difficulties were encountered during start-up.

GENERAL ORDER OF DAILY EVENTS DURING THE TESTING

For each facility tested the general order of daily events during the testing was as follows:

1. Set up the meteorological station.

2. Determine the wind direction.

3. Show the wind direction on a map of the test site and mark the location of the one upwind and three downwind sampling locations.

4. Wash the inside of each Hi-Vol with alcohol and set up the Hi-Vols upwind, downwind, and in-plant, and record the starting times and filter numbers for each one.

5. Start the daily log sheet for wind direction and velocity, dry bulb temperature, wet bulb temperature, and cloud cover.

6. Run Andersen impactor samples at the upwind, primary downwind, and all in-plant sampling locations on a random time schedule throughout the test period.

7. Periodically check all Hi-Vol samplers and fill portable generator gas tanks.

8. Collect all Hi-Vol samples.

9. Place each sample in a sterile container, label, and store in refrigerator.

10. Pack all samples in refrigerated container and ship to MRI laboratory for analysis.

ST. LOUIS INCINERATOR AND REFUSE PROCESSING PLANT

Figure B-1 is a map of the St. Louis Incinerator and Refuse Processing Plant. The property lines are from the fence on the north to the south side of the salt storage area and from the river on the east to the railroad tracks on the west. The upwind and downwind sample locations were along the property lines. An example of the sample locations is also shown in Figure B-1. The property contains: the incinerator building which houses a tipping floor, refuse receiving pit, overhead hopper loading crane, incinerator,

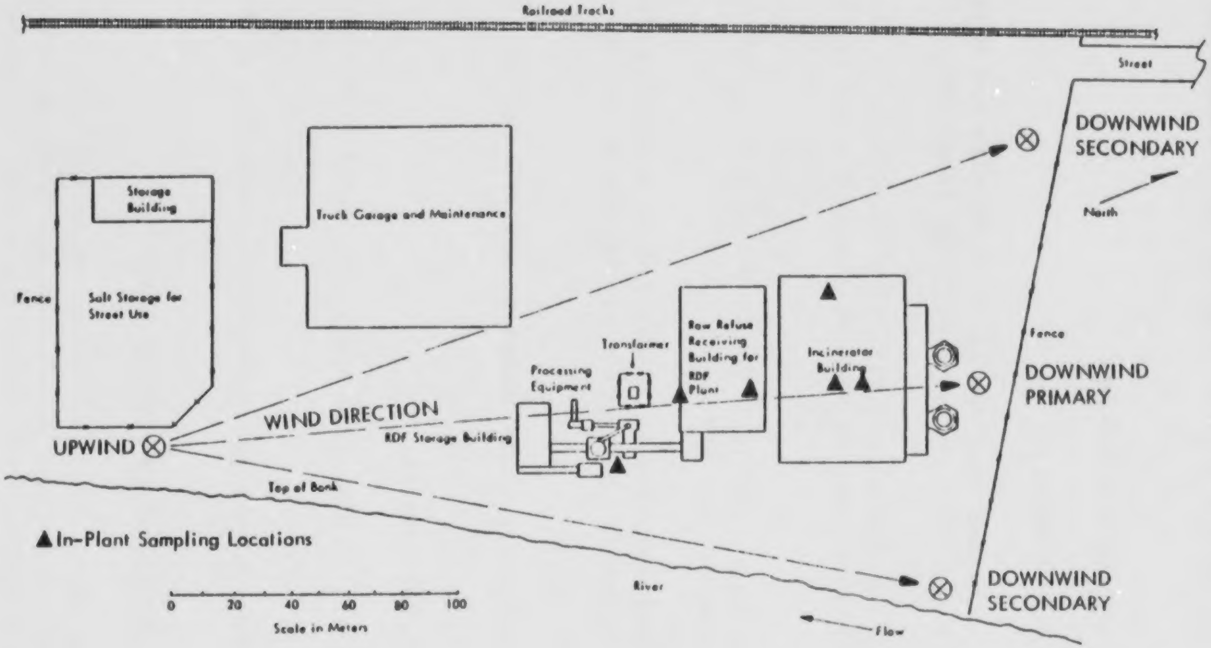

Railroad Tracks
Street
DOWNWIND SECONDARY
North
Storage Building
Truck Garage and Maintenance
Fence
Salt Storage for Street Use
Transformer
Processing Equipment
Raw Refuse Receiving Building for RDF Plant
Incinerator Building
Fence
DOWNWIND PRIMARY
WIND DIRECTION
RDF Storage Building
UPWIND
Top of Bank
In-Plant Sampling Locations
River
DOWNWIND SECONDARY
0
20
40
60
80
100
Scale in Meters
Flow

Figure B-1. Layout of incinerator and RDF plant.

scale office and administrative offices; the raw refuse receiving building for the RDF plant houses a tipping floor, operator's office, drag conveyor and shredder; the air classifier system, RDF storage building, and associated conveyors are adjacent to the raw refuse receiving building; a large truck garage and maintenance building houses all of the City of St. Louis packer trucks which deliver refuse to the facility and a maintenance area; the salt storage area is open and surrounded by a fence.

The amount of raw refuse received each test day was:

Incinerator plant

Date	Amount (Mg)	Time period
11-2-76	345.80	8:00 AM - 4:00 PM
11-3-76	376.85	8:00 AM - 4:00 PM
11-4-76	298.50	8:00 AM - 4:00 PM

RDF plant

Date	Amount (Mg)	Time period[a]
11-9-76	169.07	8:00 AM - 12:00 Noon
11-10-76	161.62	8:00 AM - 12:00 Noon
11-11-76	163.69	8:00 AM - 12:00 Noon

---

[a] Material received from 8:00 AM - 12:00 noon but was processed from 9:00 AM - 3:00 PM.

The sample locations and sampling equipment for the incinerator plant and RDF plant tests were as follows:

Incinerator plant	Sampling equipment
1. Upwind	Hi-Vol and Andersen
2. Downwind primary	Hi-Vol and Andersen
3. Downwind secondary, two locations	Hi-Vol
4. Packer truck	Hi-Vols (2)
5. Downtown St. Louis	Hi-Vol
6. Tipping floor	Hi-Vol and Andersen
7. Crane	Hi-Vol and Andersen
8. Scale office	Hi-Vol and Andersen

RDF plant	Sampling equipment
1. Upwind	Hi-Vol and Andersen
2. Downwind primary	Hi-Vol and Andersen
3. Downwind secondary, two locations	Hi-Vol
4. Downtown St. Louis	Hi-Vol
5. Tipping floor	Hi-Vol and Andersen
6. Control room	Hi-Vol and Andersen
7. Packer station	Hi-Vol and Andersen
8. Hammermill discharge	Grab sample
9. Mobile filter inlet	Impinger
10. Mobile filter outlet	Impinger
11. ADS exhaust	Hi-Vol stack sampler

The selections of the sample locations were made as follows:

Upwind - Selection was made to center this location upwind at the property line on a line across the incinerator plant (November 2 through 4, 1976), and the RDF plant (November 9 through 11, 1976), in line with the wind direction.

Downwind primary - This location was downwind at the property line on a line across the incinerator building, or the RDF plant, dependent on which facility was being tested in line with the wind direction.

Downwind secondary (2) - These two locations were at the property line and spread far enough apart on each side of the downwind primary to allow for any normal variation in wind direction.

Packer truck - This sample location was selected to determine the relative bacteria and virus levels of the packer trucks. The actual sampling location was at the back of the truck above where the refuse was loaded.

Downtown St. Louis - This sample location was selected to determine the relative bacteria and virus levels for downtown St. Louis compared to upwind and downwind at the incinerator and RDF plant.

Incinerator plant tipping floor - This sampling location was selected because the raw refuse received was accumulated there and the dust generated by dumping the raw refuse would most likely be higher in this area compared to other plant areas. The sampling location was near the center of the receiving pit ledge.

Incinerator plant crane - This location was directly above the receiving pit on the crane which picked up the refuse, lifting it to the incinerator loading bins which were at the crane level. It was selected because it seemed likely to have a high bacteria count, if one existed, because of the close proximity to the raw refuse and the crane operator was in this area for long periods of time.

Incinerator plant scale office - This location was adjacent to the tipping floor at the west end of the incinerator building. It was selected because of its close proximity to the tipping floor and because the office was occupied by employees much of the time.

RDF plant tipping floor - This sampling location was selected because the raw refuse received was accumulated there and the dust generated from the raw refuse would most likely be at a higher level in this area compared to other plant areas. The sampling location was along the north wall directly across from the large pile of raw refuse.

RDF plant control room - This sampling location was selected because the control room was adjacent to the drag conveyor and the operator was in the control room for long periods of time.

RDF plant packer station - This sampling location was selected because the RDF was being loaded into trailer trucks and there was a considerable amount of visible particulate from this operation. Also, this location was near the air classifier system and a conveyor, both of which were emitting particulate. These pieces of processing equipment and the sampling location were outside.

RDF plant hammermill discharge - This sample location was selected to determine the bacteria level of the RDF. The samples taken here were grab samples of the RDF, taken three times each day.

RDF plant mobile filter inlet and outlet - These were special samples designed to test the efficiency of the mobile filter for removal of bacteria.

RDF plant air classifier exhaust - This sampling location was selected to determine the B and V level of the air classifier exhaust being released into the air, to verify previous testing.

WASTEWATER TREATMENT PLANT

Figure B-2 is a map of the wastewater treatment plant. The map shows the plant property and its facilities. The property lines are at the fence surrounding the facility. An example of the sampling locations is also shown in Figure B-2. The property contains: the office and laboratory building which houses the administrative offices and a laboratory; the bar screen on incoming main sewer line is open to atmosphere; the grit chamber is enclosed; the sludge holding tank is open to atmosphere next to the chlorination

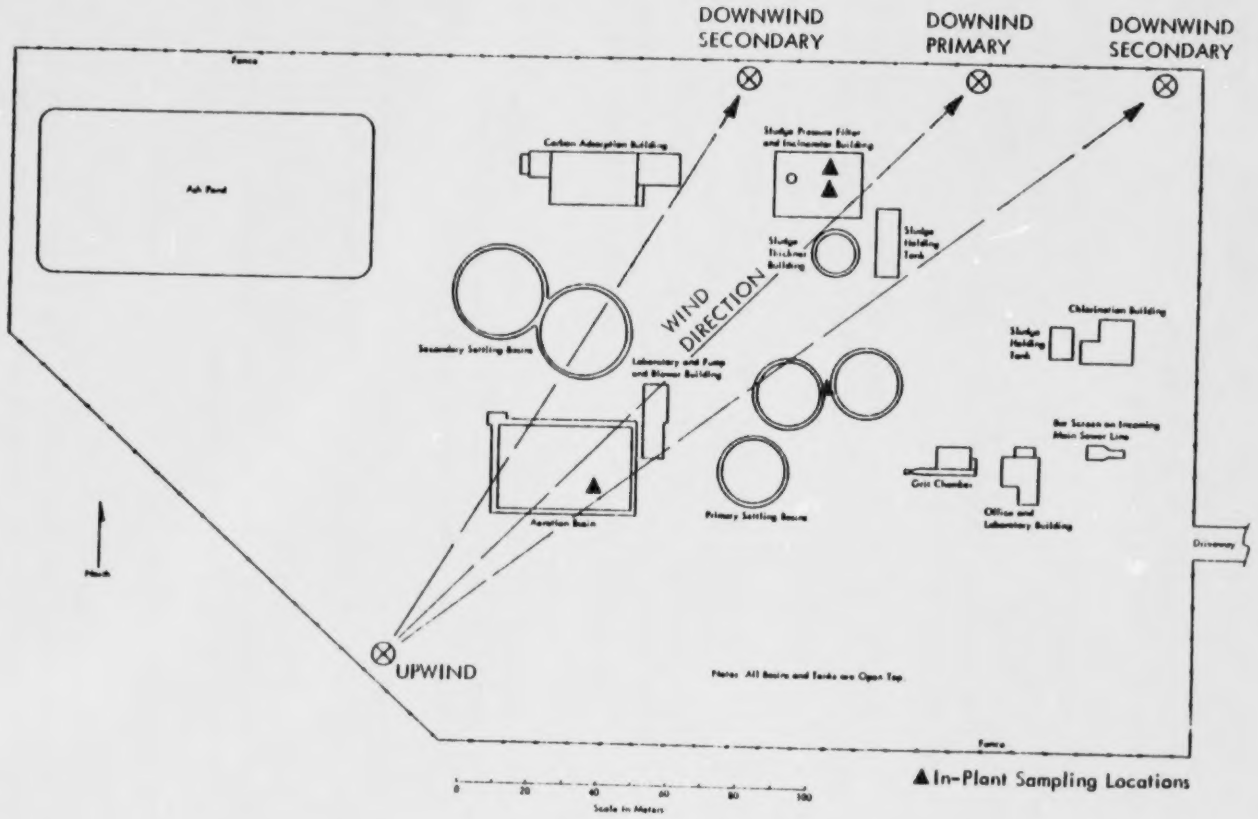

DOWNWIND SECONDARY
DOWNIND PRIMARY
DOWNWIND SECONDARY
Fence
Ash Pond
Carbon Adsorption Building
Sludge Pressure Filter and Incinerator Building
Sludge Thickner Building
Sludge Holding Tank
WIND DIRECTION
Secondary Settling Basins
Laboratory and Pump and Blower Building
Chlorination Building
Sludge Holding Tank
Bar Screen on Incoming Main Sewer Line
Grit Chamber
Office and Laboratory Building
Aeration Basin
Primary Settling Basins
Driveway
North
UPWIND
Note: All Basins and Tanks are Open Top
Fence
▲ In-Plant Sampling Locations
0
20
40
60
80
100
Scale in Meters

Figure B-2. Layout of wastewater treatment plant.

building; the sludge holding tank is open to atmosphere next to the sludge thickener building and the sludge pressure filter and incinerator building; the sludge pressure filter and incinerator building houses the press which removes the liquid from the sludge and forms the cake, the conveyors and delumper in the basement and the incinerator; the carbon adsorption building is enclosed; the laboratory, pump, and blower building is enclosed; the primary settling basins and secondary settling basins are open to atmosphere; and ash pond is open to atmosphere.

The amount of wastewater received each test day during the test period was:

Date	Amount (liters)	Time period
11-16-76	1,920,000	9:11 AM - 3:30 PM
11-17-76	2,000,000	8:30 AM - 3:15 PM
11-18-76	2,280,000	8:40 AM - 4:00 PM

The sample locations and the sampling equipment for each location were as follows:

Sampling location	Sampling equipment
1. Upwind	Hi-Vol and Andersen
2. Downwind primary	Hi-Vol and Andersen
3. Downwind secondary, two locations	Hi-Vol
4. Primary settling basin	Hi-Vol and Andersen
5. Aeration basin	Hi-Vol and Andersen
6. Pressroom	Hi-Vol and Andersen
7. Pressroom basement	Hi-Vol and Andersen

The selections of the sample locations were made as follows:

Upwind - Selection was made to place this location upwind at the property line on a line across the basins and the incinerator building, in line with the wind direction.

Downwind primary - This location was downwind at the property line on a line across the basins and the incinerator building, in line with the wind direction.

Downwind secondary (2) - These two locations were at the property line and spread far enough apart on each side of the downwind primary to allow for any normal variation in wind direction.

Primary settling basin - This sampling location was selected because it was an open processing area and the wastewater contained more solids than the fluid in the secondary settling basins. The sampling location was between two of the three primary settling basins.

Aeration basin - This sampling location was selected because it was a large open processing area. The basin had walkways directly overhead and the sampling location was on the walkway.

Pressroom - This sampling location was selected because it was the final processing stage, was enclosed in a building, and had plant personnel present for a large portion of their work shift. The sampling location was between the presses. The Andersen samples were taken for 30 sec, either just prior to opening the presses to drop the cakes, or while the presses were open while the Hi-Vol sampler ran continuously for 6 hr.

Pressroom basement - This sampling location was selected because it was directly under the pressroom and the cakes were dropped on an open conveyor which then passed through a delumper that was also in the basement. The sampling location was between the conveyors. The Andersen samples were taken as the cake was being dropped.

WASTE TRANSFER STATION

Figure B-3 is a map of the waste transfer station. The map shows the plant property and its facilities. The property line is designated on the map and is shown as a continuous line around the facility. An example of a sampling location is also shown in Figure B-3. The property contains: the administration and truck maintenance building which houses the administrative offices and the truck maintenance shop; the refuse transfer building which houses the tipping floor and the packer ramp that is at the southwest corner of the building and below the tipping floor.

The amount of raw refuse received each day during the test period was:

Date	Amount (Mg)	Time period
11-22-76	329.18	8:00 AM - 4:30 PM
11-23-76	291.21	8:00 AM - 4:30 PM
11-24-76	313.98	8:00 AM - 4:30 PM

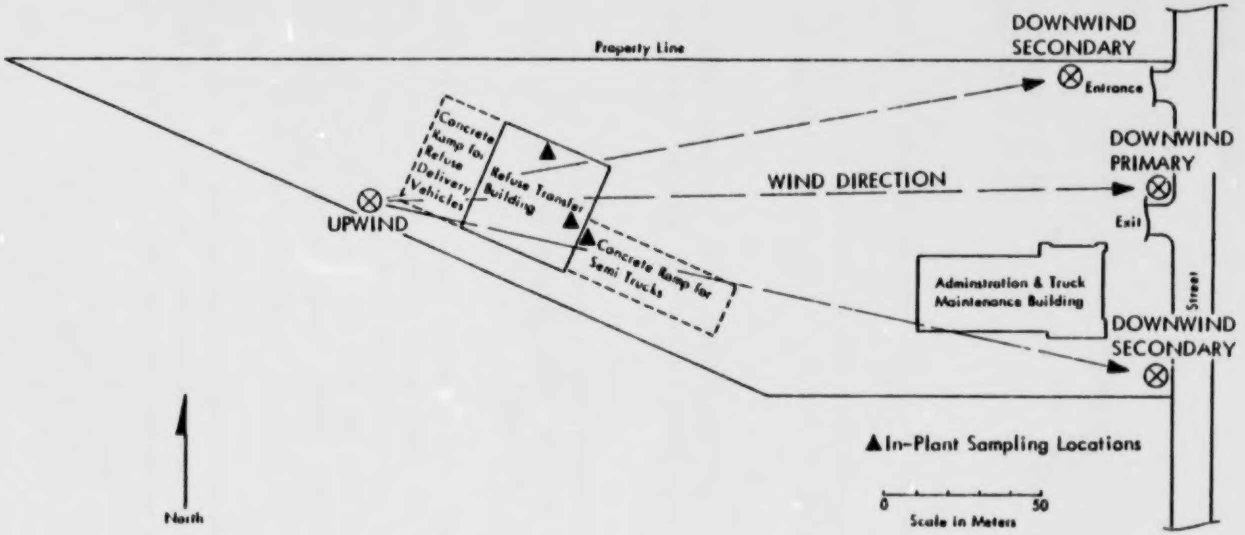

Property Line
DOWNWIND SECONDARY
Entrance
DOWNWIND PRIMARY
WIND DIRECTION
Exit
Concrete Ramp for Refuse Delivery Vehicles
Refuse Transfer Building
UPWIND
Concrete Ramp for Semi Trucks
Administration & Truck Maintenance Building
Street
DOWNWIND SECONDARY
▲In-Plant Sampling Locations
0
50
Scale in Meters
North

Figure B-3. Layout of waste transfer station.

The sample locations and the sampling equipment for each location were as follows:

Sampling location	Sampling equipment
1. Upwind	Hi-Vol and Andersen
2. Downwind primary	Hi-Vol and Andersen
3. Downwind secondary, two locations	Hi-Vol and Andersen
4. Tipping floor, north wall	Hi-Vol and Andersen
5. Tipping floor, east wall	Hi-Vol and Andersen
6. Packer ramp	Hi-Vol and Andersen

The selections of the sampling locations were made as follows:

Upwind - This selection was made to place this location upwind at the property line on a line across the refuse transfer building, in line with the wind direction.

Downwind primary - This selection was made to place this location downwind at the property line, on a line across the refuse transfer building, in line with the wind direction.

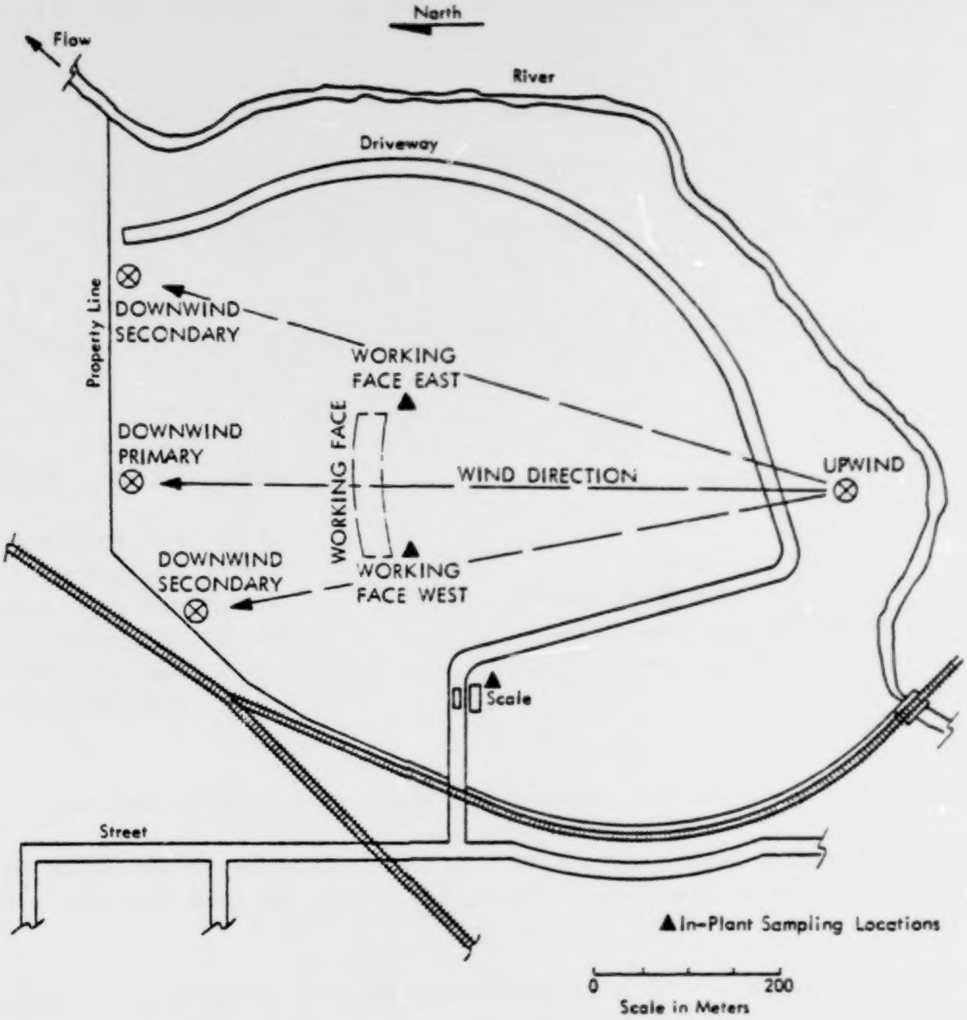
Downwind secondary (2) - These two locations were at the property line and spread far enough apart on each side of the downwind primary to allow for any normal variation in wind direction.

Tipping floor, north wall and tipping floor, east wall - These sampling locations were selected because they were inside the transfer building and alongside the area where the raw refuse received was accumulated and, therefore, would be more likely to detect any higher levels of bacteria associated with handling of the raw refuse. Also, there was an operator driving the front-end loader who was in the area most of his work shift.

Packer ramp - This sampling location was selected because as the packer forced the raw refuse into the covered trailer, it emitted a large amount of particulate and there was an operator present who transferred the trailers and cleaned up the area.

SANITARY LANDFILL

Figure B-4 is a map of the sanitary landfill. The map shows the plant property and the location of the scale office and the working face. An example of a sampling location is also shown in Figure B-4. The only building on the property is the scale office. The location of the working face is



North
Flow
River
Driveway
Property Line
DOWNWIND SECONDARY
WORKING FACE EAST
DOWNWIND PRIMARY
WORKING FACE
WIND DIRECTION
UPWIND
DOWNWIND SECONDARY
WORKING FACE WEST
Scale
Street
▲In-Plant Sampling Locations
0
200
Scale in Meters

Figure B-4. Layout of sanitary landfill.

ever changing and the working face shown on the map is the location during the testing program.

The amount of raw refuse received each day during the test period was:

Date	Amount (Mg)	Time period
11-29-76	792	8:00 AM - 5:00 PM
11-30-76	787	8:00 AM - 5:00 PM
12-1-76	786	8:00 AM - 5:00 PM

The sample locations and the sampling equipment for each location were as follows:

Sampling location	Sampling equipment
1. Upwind	Hi-Vol and Andersen
2. Downwind primary	Hi-Vol and Andersen
3. Downwind secondary, two locations	Hi-Vol and Andersen
4. Working face, east	Hi-Vol and Andersen
5. Working face, west	Hi-Vol and Andersen
6. Scale	Hi-Vol and Andersen

The selections of the sampling locations were made as follows:

Upwind - This selection was made to place this location upwind at the property line, on a line across the working face, in line with the wind direction.

Downwind primary - This selection was made to place this location downwind at the property line, on a line across the working face, in line with the wind direction.

Downwind secondary (2) - These two locations were at the property line and spread far enough apart on each side of the downwind primary to allow for any normal variation in wind direction.

Working face, east and working face, west - These sampling locations were selected because they were adjacent to the working face where the raw refuse was received and then buried. The sampling locations had to be at the outer edges of the working face because the packer trucks were dumping and they were moving the raw refuse around with heavy equipment and would have destroyed the sampling equipment if it had been any closer.

Scale - This sampling location beside the scale was selected because all of the vehicles delivering refuse stopped at the scale to be weighed and this increased the exposure of the scale operator to any dust or bacteria which might be emitted from the raw refuse.

SAMPLE HANDLING

The methodology for the sample handling was dependent upon the type of sampling equipment being used. The following are descriptions of the procedures followed for each type of sampling equipment used.

Hi-Vol Samplers

The Hi-Vols were equipped with a screen which the filter was placed on, and an open metal frame with a foam gasket to seal off the edges of the filter and hold it in place. The filters were placed in folders and sealed in heavy envelopes. They were then autoclaved to sterilize the entire package. The technician starting up the Hi-Vol would wipe the filter screen, metal frame, and surrounding area inside the Hi-Vol with lint-free chemical wipes saturated with isopropyl alcohol to sterilize the unit. He would then open the envelope, and wearing a sterile vinyl glove, he would remove the filter, place it on the screen, and secure it with the metal frame. The thin film of isopropyl alcohol had dried before the filter was placed on the screen and great care was taken with the filter to not touch it, or contaminate it, in any way. The Hi-Vol was then started and the Hi-Vol and filter numbers and time were recorded. The Hi-Vols were normally powered by portable generators which might stop for some reason, so a clock was also plugged into the generator to accurately record the time in case it stopped. The generators were checked approximately each 1-1/2 hr; fuel was added and any downtime recorded.

When the sampling time was completed, the technican would shut off the unit, and wearing a sterile vinyl glove, he would remove the filter from the Hi-Vol and place it in a sterile envelope and return it to the mobile laboratory at the test site. The lab technician would check the field laboratory log sheet to see what the dispensation was for that sample. Example: either the entire filter was to be submitted for L1, or L2 analysis, or it would be quartered for L2, microbial morphology, trace metal, and physiochemical morphology analyses. He would then, wearing sterile vinyl gloves, prepare the sample and place it in a sterile plastic bag and seal it. He would then attach a label, which identified the sample and the analysis to be performed, to the plastic bag and write the sample number on the bag in case the label should become detached. The sample was then placed in the refrigerator for storage until all of the samples were prepared.

Hi-Vol Sampler with Precyclone

The Hi-Vol sampler with precyclone was identical to the standard Hi-Vol sampler except for the addition of the precyclone. The only procedural difference in preparing the unit for start-up was to clean out and sterilize the precyclone with isopropyl alcohol in addition to the filter screen and surrounding area. The Hi-Vols with precyclone were used for in-plant testing, and there was electrical power available which eliminated the need for portable generators and clocks. The units were, however, checked at approximately 1-1/2 hr intervals, the same as the standard Hi-Vols. The rest of the sample handling procedures were identical to the standard Hi-Vols.

Andersen Impactor with Backup Impinger

The mobile laboratory at the test site was equipped with a cabinet which contained a high frequency ultraviolet light. The Andersen impactors and impingers used in this test program were sterilized in the UV cabinet. The lids for the agar plates used in the Andersen impactors were sterilized in the UV cabinet, while the plates were in the Andersen. This was done to avoid contaminating the sample after it was recovered from the Andersen. The Andersens were loaded with the agar plates and a stopper placed in the inlet and outlet. The impingers were additionally sterilized with isopropyl alcohol and thoroughly rinsed twice with Hank's balanced salt solution. The impingers were then filled with 100 ml of Hank's balanced salt solution and sealed until assembled with the Andersen impactor. The above preparations were made before each Andersen sample was taken.

The Andersen samples were operated by a vacuum pump equipped with a limiting orifice to control the flow at 0.466 liters/sec. The vacuum hose was clamped shut, attached to the vacuum pump, the stopper was removed, the hose clamp released, and the timing started. At the end of the sampling time, the hose was clamped, removed from the vacuum pump, and then released. The stopper was replaced and the Andersen unit returned to the mobile laboratory.

The laboratory technician removed the agar plates one at a time; immediately covering the plates with the sterile lids. The agar plates were each labeled for identification and taped together as a set. The paper label identifying the sample and containing the dispensation instructions was attached to the set and stored in the refrigerator until all of the samples were prepared. The lab technician then poured the impinger solution into a sterile glass bottle and sealed it with a cap. The sample number was then written on the bottle in ink and a paper label identifying the sample and containing the dispensation instructions was attached to the bottle. The sample was then stored in the refrigerator until all of the samples were prepared.

Impinger

Impingers were used alone to sample the mobile filter inlet and outlet at the RDF plant. The inlet was sampled with two impingers in series and the outlet with a single impinger. The sterilization, handling techniques, and sample recovery were identical to the methods used for the backup impinger for the Andersen impactor. However, these inlet/outlet impingers were operated for 6 hr each day.

Sample Shipment

When all of the samples had been packaged and labeled, they were placed in an insulated shipping carton with plastic enclosed ice packages. The plastic enclosed ice packages kept the fluid contained as it melted so they could be reused and would not damage the samples. The void spaces were filled with packing to hold the contents in place during shipment and prevent damage to the samples. The container was strapped shut and sent by air express to MRI, where it was received the following morning for sample analyses.

APPENDIX C

LABORATORY ANALYSIS METHODOLOGY FOR BACTERIA AND VIRUS

BACTERIA METHODOLOGY

Sample Preparation

The filter pads from the Hi-Vol samples were prepared for assay by homogenizing in a sterile Waring blender with sterile distilled water sufficient to produce a 1:100 dilution using a blending time of 30 sec. Aliquots of this slurry were then transferred directly to culture media or used to prepare additional dilutions. The pH of each slurry was checked after all bacteriological samples had been taken.

Total Plate Count

Dilutions of the filter pad slurry were prepared in sterile distilled water and these were then transferred in duplicate to petri dishes which were poured with plate count agar (Difco) and incubated at 35°C for 48 hr. A longer incubation at a lower temperature might have given slightly higher counts, but because mold spores were present in large numbers it was not possible to extend the incubation time beyond 48 hr without overgrowth of fungi.

Isolated colonies were picked from representative plates and transferred to slants of trypticase soy agar. The cultures were then used for determination of morphology and gram-reaction.

Standard Total Coliform MPN Tests

Presumptive--

The presumptive test was conducted using lauryl tryptose broth as the medium. Five fermentation tubes each of 10, 1, and 0.1 ml of the filter pad slurry were prepared and were incubated at 35 $\pm$ 0.5°C. At the end of 24 hr, each tube was examined and those showing gas were recorded. Those tubes in which no gas was observed after 24 hr were reincubated for an additional 24 hr (total 48). Formation of gas within 48 hr constituted a positive presumptive test.

Confirmation--

All tubes showing gas in 24 or 48 hr in the presumptive test were subcultured in brilliant green lactose bile broth. These tubes were then incubated for 48 hr at 35 ± 0.5°C. The formation of gas in the tubes within 48 hr consistuted a positive confirmed test.

Completion--

Samples of each tube of brilliant green lactose bile broth showing gas were streaked onto eosin-methylene-blue agar plates. These plates were incubated at 35 ± 0.5°C for 24 hr.

Typical colonies were picked and transferred to nutrient agar slants and were examined after 24 hr by use of the Gram-Stain technique. The cultures which were gram-negative were considered to be coliform.

Fecal Coliform MPN

All tubes showing gas in the presumptive coliform test were used to inoculate tubes of EC medium. The inoculated tubes were then incubated in a water bath at 44.5 ± 0.2°C for 24 hr. If gas was produced in 24 hr the test was considered positive and indicated the presence of coliform of fecal origin. MPN tables were used to determine probable densities in the original sample.

Subcultures were made from positive tubes on eosin-methylene-blue agar and typical colonies on the solid medium were then transferred to nutrient agar slants and used to perform serological typing.

Serological Typing of *E. coli*

Subcultures from nutrient agar slants were made to brain heat infusion agar of typical fecal coliform isolates. Then cultures were incubated overnight and on the following day portions of each culture were tested against *E. coli* OK antiserum poly by the slide agglutination technique recommended by Difco Laboratories. (1)

Salmonella

Tests for the presence of members of the genus *Salmonella* were conducted using both direct inoculation of filter pad slurry to selective agars such as MacConkey's and brilliant green and by enrichment techniques using selenite broth.

When selenite broth enrichment was used, 24 or 48 hr enrichments from the selective broth were transferred to MacConkey's and brilliant green agars.

Typical appearing colonies were then picked and transferred to triple sugar iron agar (TSI). All isolates giving reactions typical of Salmonella on TSI agar slants were then transferred to slants of heart infusion agar and used for serological testing.

The isolates were first tested serologically using the slide agglutination technique (Difco) and Salmonella polyvalent antisera. Any positive reactors were then tested using Salmonella group specific antisera.

Fecal Streptococci

Fecal streptococci were enumerated by a pour plate technique utilizing KF Streptococci agar. This direct count procedure was accomplished by plating 1, 0.1, and 0.01 ml samples of the filter pad slurry with KF agar and incubating the solidified plates at 35 ± 0.5°C for 48 hr.

Klebsiella

The presence of species of *Klebsiella* was determined by picking typical appearing colonies from MacConkey's agar plates prepared by inoculation of dilutions from the filter pad slurry. These isolates were transferred to additional MacConkey plates for determining the purity of the isolate. Well isolated colonies from the pure culture were then transferred to slants of brain-heart infusion agar and these cultures were used to determine the biochemical reactions of the isolates. All isolates possessing biochemical characteristics similar to those reported for *Klebsiella* species were tested using polyvalent *Klebsiella* antiserum.

Staphylococcus aureus

The presence of *S. aureus* was determined by plating aliquots of the sample slurry directly onto Staphylococcus 110 medium agar plates (Difco). These plates were incubated at 37°C for 24 and 48 hr and all typical appearing colonies were transferred to brain-heart infusion slants. After overnight growth the isolates were tested for production of coagulase by the standard tube method.

VIRUS METHODOLOGY

Samples for virus analysis were concentrated by two methods. Initially, the samples were concentrated using the hydroxyapatite method. However, this method was found to be inefficient, and later samples were concentrated by the dextran sulfate-polyethylene glycol phase separation.

Concentrated samples were analyzed using the monolayer plaque assay technique according to Schmidt (6) with only minor modifications. In all samples, the heteroploid monkey kidney cell line, LLC-MK_2 was used for the monolayers. The technique was tested using an attenuated poliovirus Type I culture with good results.

Virus Concentration Procedures

At first, virus concentrations were performed on Hi-Vol filter pad samples and impingers solutions with the hydroxyapatite flocculation-precipitation method as conducted in the earlier 1975 St. Louis Test Program. (4) However, reproduction of the earlier investigator's method in detail resulted in the absence of floc formation. As a result, the procedure was modified such that floc was formed, and this modified procedure is repeated here in detail (see Table C-1). Using this procedure, each filter was weighed and diluted 1:200 (w/w) with sterile distilled water. The sample was then homogenized using a Waring blender at high speed for a minimum of 30 sec. Hydroxyapatite precipitate was formed to retain the viruses with the solids phase by adding 25 ml/liter sample of each 0.5 M $CaCl_2$ and 0.5 M Na_2HPO_4. The sample was then blended briefly at low speed to effect contact with the viruses. The homogenate was suction filtered through Whatman No. 1 filter paper supported by a Buchner funnel. A slurry was prepared of the precipitate and filter by mixing the sample with a spatula after addition of 40 ml 0.3 M Na_2EDTA at pH 7.0. The sample was again filtered through Whatman No. 1 filter paper with suction filtration. The filtrate was then added to a dialysis bag and dialyzed against distilled water for 5 hr with constant stirring by a magnetic mixer. After 5 hr, the contents of the dialysis tube was poured into a 250 ml centrifuge tube to which was added 3 to 4 ml of each 0.5 M $CaCl_2$ and 0.5 ml Na_2HPO_4 to form hydroxyapatite floc. The sample was mixed and then centrifuged at 653 x g at 4°C for 15 min. The supernatant was poured off and 3 ml of 0.3 M Na_2EDTA at pH 7.0 was added to the precipitate. The solution was again added to a dialysis bag and dialyzed overnight against distilled water. The contents of the dialysis bag was then stored in small bottles at -100°C until monolayer plaque assay could be conducted.

Potential areas for sample loss, i.e., virus loss, are numerous in the hydroxyapatite precipitation method. These areas include the following:

1. Numerous handling steps result in frequent losses of sample.
2. Loss of virus along with filtrate during first suction filtration.
3. Loss of virus by entrapment on filter during second filtration.
4. Adsorption to dialysis tubing during dialysis steps.
5. Loss in supernatant after centrifugation steps.
6. Overall inefficiency of the calcium phosphate to adsorb and retain viruses.

TABLE C-1. FLOW SHEET FOR VIRAL CONCENTRATION PROCEDURES OF AEROSOL SAMPLES ON HI-VOL FILTERS[a] (Hydroxyapatite method)

Filter with particulate sample.
Weighed, diluted 1:200 (w/w) with distilled H_2O, and homogenized with Waring blender

↓

Add 25 ml/liter 0.5 M $CaCl_2$
25 ml/liter 0.5 M Na_2HPO_4
Blend on low speed.

↓

Suction filter through Whatman No. 1 filter supported by Buchner funnel.

→ Discard filtrate

↓

Add 40 ml 3.0 M Na_2EDTA (pH 7.0) to precipitate
Prepare slurry of precipitate and filter.

↓

Suction filter through Whatman No. 1 filter supported by Buchner funnel.

→ Discard particulate matter and filter

↓

Dialyze filtrate for 5 hr against distilled H_2O with constant stirring

→ Discard dialysate

↓

Contents of dialysis bag

↓

Add 3 to 4 ml each of 0.5 M $CaCl_2$ and 0.5 M Na_2HPO_4.
Shake well to form calcium phosphate floc.
Centrifuge at 653 x g at 4°C for 15 min.

→ Discard supernatant

↓

Dissolve precipitate in 3 ml 0.3 M Na_2EDTA at pH 7.0

↓

Dialyze overnight against distilled water

→ Discard dialysate

↓

Contents of dialysis bag

↓

Tissue culture assay for virus
(Monolayer Plaque Assay)

---

[a] This procedure is also used for impinger samples by excluding the initial homogenization step.

Because of these six areas for virus loss, a comparison using bacteriophage T-1 as a virus model was made between the modified hydroxyapatite method and the phase separation method as delineated in Table C-2. Actual field samples were seeded with a known concentration of phage T-1, processed, and the resulting concentrates assayed using the agar overlay method with *Escherichia coli B* serving as the host indicator organism. The phase separation method was found to be much superior to the hydroxyapatite method with recovery percentages of 18.2 and 0.1%, respectively. After we had obtained an attenuated poliovirus I culture, the phase separation method was found to have a concentration efficiency of 23.9%. Therefore, only the phase separation method was used for the balance of the virus samples.

A large number of virus concentration procedures have been described in the literature. These concentration procedures can be divided into seven main groups. (5) These are the following:

1. Sample incorporation;
2. Ultrafiltration;
3. Freezing;
4. Two-phase separation;
5. Ultracentrifugation;
6. Electrophoresis; and
7. Adsorption and elution.

Of the many virus concentrations available, none of them at the present time can be considered superior in all applications because of the many variables involved. (5) The two chief variables that the investigator must take into account are the physical nature of the sample and the hypothetical number of viruses one expects to be in the sample. These two variables alone can eliminate many of the current methods.

The phase separation method was chosen over the other methods for several reasons. The method seemed the most promising to use with samples collected on filter media. The method could be used with small or large volumes of sample. The procedure is not difficult and time-consuming, thus being conducive to processing large numbers of samples. Finally, the method is relatively inexpensive.

TABLE C-2. FLOW SHEET FOR VIRAL CONCENTRATION PROCEDURES OF AEROSOL SAMPLES ON HI-VOL FILTERS[a]

(Phase separation method)

Filter with particulate sample.
Weighed, diluted 1:100 (w/w) with distilled H_2O, and homogenized with Waring blender
↓
Centrifuge at 1,080 x g for 15 min at 4°C
→ Discard Ppt.
↓
Neutralize supernatant to pH 7.2
↓
Add each of the following sequentially after each is thoroughly dissolved

1.75% (w/w) (0.3 m) Dry Sodium Chloride
0.2% (w/w) Sodium Dextran Sulfate 2000
6.43% (w/w) Polyethylene Glycol 4000
↓
Allow to mix 1 hr using a magnetic stirrer.
↓
Transfer mixture to separatory funnel and store at 4°C for 18 to 24 hr.
↓
Collect bottom and interphase portions.
↓
Follow one of the two following methods:

Method 1 - (Shuvall (2))
- To bottom and interphase portions, add KCl to 0.7 M to ppt. dextran sulfate.
- Centrifuge at 2,500 g for 10 min at 4°C.
- To supernatant, add 1.0 ml anesthetic grade diethyl ether per 4 ml reconcentrate.
- Shake mixture and hold at 4°C for 18 hr to kill contaminating bacteria and molds.
- Tissue culture assay for viruses.

Method 2 - Alternative Double Concentration (Fields (3))
- To bottom and interphase portions, add NaCl until final concentration of 1.0 M is reached.
- Mix for 1 hr followed by an 18 hr interval at 4°C.
- Centrifuge for 10 min at 120 x g at 4°C.
- Withdraw top and interphase portion with pipet.
- Add 1.0 ml anesthetic grade ether per 4.0 ml reconcentrate.
- Tissue culture assay for viruses.

---

[a] This procedure may be modified to process impinger samples by eliminating the initial homogenization and centrifugation steps.

Table C-2 presents the phase separation method, which like the hydroxyapatite method, commences with a homogenized filter sample. The sample is then centrifuged to remove the filter fibers. The balance of the phase separation method is explained in Table C-2.

REFERENCES FOR APPENDIX C

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APPENDIX D

IITRI REPORT ON ASBESTOS ANALYSIS

April 15, 1977

Paul G. Gorman
Senior Chemical Engineer
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

Subject: Final Report - IITRI Project No. C8327
"Testing Emission Samples from Municipal
Waste Disposal"
MRI Project No. 4033-L(1)

Dear Dr. Gorman:

Attached are the analyses of fibers present in your samples ADS-4-1 and ADS-2-4. All other samples submitted along with your letter of December 16, 1976 could not be analyzed for fibers because the collection substrate was glass fiber filter paper. All samples are being returned to you along with this report.

The procedure used for determining the fiber concentration in samples ADS-4-1 and ADS-2-4 was as follows: A known, weighable quantity, approximately 10 mg of dust was dispersed in 500 ml of filtered distilled water. Aerosol OT and sonification were used as dispersion aids. We attempted to obtain a representative sample of this diverse material; but, can not be sure of our success. Various small aliquots of the dispersed material were filtered through 47 mm, 0.22 μm pore size, Nuclepore filters yielding a uniform deposit. Several 3 mm discs were cut from the Nuclepores and the deposit transferred to carbon coated, electron microscope grids by dissolving the Nuclepore filters with chloroform in a Jaffe wick washer. The grids were then examined under the transmission electron microscope and the fibers (3:1 aspect ratio) counted and their length (L) and width (W) measured. Electron diffraction patterns and elemental analysis by non-dispersive X-rays were used to determine if the fibers observed were asbestos. For sample ADS-4-1, all fibers were checked for their electron diffraction pattern and elemental analysis, fifteen out of nineteen fibers were asbestos. For sample ADS-2-4, 18% of the total fibers observed were checked for their electron diffraction pattern and elemental analysis. All were determined to be asbestos and it was, therefore, assumed that all the fibers observed were asbestos.

The fiber count from the samples was converted to fiber mass using two formulas:

For magnesium-silicates:

$$M_f = \pi/4 \times L \times W^2 \times 2.6 \text{ g/c.c.} \times 10^{-6} \ \mu\text{g} \qquad (1)$$

For magnesium-silicates with iron:

$$M_f = L \times W^2 \times 3.25 \text{ g/c.c.} \times 10^{-6} \ \mu\text{g} \qquad (2)$$

The mass of fiber per mass of material was calculated as follows:

$$\% \text{ Fiber Mass} = \Sigma M_f \times \frac{1}{A_G} \times \frac{1}{N_G} \times \frac{A_F}{M_s} \times 100 \qquad (3)$$

ΣM_f = summation of the mass of individual fibers, µg

A_G = area of E.M. grid opening, 7.2×10^{-5} cm^2

N_G = number of grid openings scanned

A_F = effective filtration area, 9.6 cm^2

M_S = mass of sample filtered, µg

Using the above formulae, sample ADS-4-1 was found to contain 1.6% asbestos and sample ADS-2-4 contained 0.46% asbestos.

Most of our clients are interested in the distribution of fiber size by number. It is uncommon to convert to mass as requested in your letter and this step required considerable time. As you will know, the conversion is influenced greatly by the presence of a few extremely large fibers.

Very truly yours,

Therese Philippi

Therese Philippi
Assistant Chemist
Fine Particles Research

Approved by,

John D. Stockham

John D. Stockham
Science Advisor
Manager
Fine Particles Research

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TABLE D-1. ANALYSIS OF SAMPLE AIR CLASSIFIER-4-1 FOR ASBESTOS FIBERS
(E.M. magnification 20,000 times, Grid A5
Sample weight filtered: 35.6 µg)

Grid Opening	Fiber Number	Fiber Dimension, µm		Electron Diffraction Pattern				X-ray Analysis, Elements Present	Is Fiber Considered Asbestos
		Width	Length	Crystalline	Non Crystalline	Possible Asbestos	Ambiguous		
1	1	.38	2.50	✓		✓		Mg,Si,Fe	Yes
	2	.06	4.00	✓		✓		Mg,Si	Yes
	3	.06	3.69	✓		✓		Si	Amb
	4	.06	2.50		✓			-	No
	5	.06	.62	✓		✓		Mg,Si	Yes
	6	.44	10.63	✓		✓		Mg,Si,Fe	Yes
	7	.06	2.50	✓		✓		Mg,Si	Yes
2	8	.31	5.31	✓		✓		Mg,Si	Yes
	9	.50	5.62		✓				No
	10	.19	63.44	✓				Mg,Si	Yes
	11	.06	3.25	✓			✓	Mg,Si	Yes
	12	.06	.75	✓			✓	Mg,Si	Yes
	13	.06	1.12	✓			✓	Mg,Si	Yes
	14	.25	6.87	✓		✓		Mg,Si	Yes
	15	.19	.62	✓			✓		No
	16	.06	3.38	✓		✓		Mg,Si	Yes
	17	.12	1.62	✓		✓		Mg,Si	Yes
	18	.06	.44	✓		✓		Mg,Si	Yes
	19	.31	2.31	✓		✓		Mg,Si,[illegible],Fe	Yes

TABLE D-2. ANALYSIS OF SAMPLE AIR CLASSIFIER-2-4 FOR ASBESTOS FIBERS (E.M. magnification 20,000 times, Grid D3 and D5 Sample weight filtered: D3-100 μg; D-5 400 μg)

Grid Opening	Fiber Number	Fiber Dimension, μm		Electron Diffraction Pattern				X-ray Analysis Elements Present	Is Fiber Considered Asbestos
		Width	Length	Crystalline	Non Crystalline	Possible Asbestos	Ambiguous		
1*	1	.06	1.75						Yes
	2	.06	2.38						Yes
	3	.12	8.44	✓		✓		Mg,Si	Yes
	4	.06	4.06						Yes
	5	.50	1.94						Yes
	6	.06	1.88						Yes
	7	.12	9.06						Yes
	8	.06	2.69						Yes
	9	.12	3.81	✓		✓		Mg,Si	Yes
	10	.06	1.69	✓		✓		Mg,Si	Yes
	11	.03	1.25					Mg,Si	Yes
	12	.06	2.50						Yes
	13	.06	2.06						Yes
	14	.06	1.12						Yes
	15	.06	3.62						Yes
	16	.19	17.81						Yes
	17	.12	7.50						Yes
2*	18	.06	2.56						Yes
	19	.03	4.69						Yes
	20	.06	1.75	✓		✓		Mg,Si	Yes
	21	.12	2.56	✓		✓		Mg,Si	Yes
	22	.12	6.36	✓		✓		Mg,Si	Yes
	23	.03	4.69	✓		✓		Mg,Si	Yes
	24	.44	4.38	✓		✓			Yes
	25	.12	.75						Yes
	26	.03	2.50	✓		✓			Yes
	27	.25	2.50	✓		✓			Yes
	28	.06	1.06	✓		✓		Mg,Si	Yes
	29	.03	2.50	✓		✓		Mg,Si	Yes
	30	.06	3.00	✓		✓		Mg,Si	Yes
	31	.03	4.44						Yes
	32	.25	1.81						Yes
	33	.19	4.38						Yes
1**	34	.19	2.94						Yes
	35	.19	3.38						Yes
	36	.19	1.69						Yes
	37	.12	4.38	✓		✓		Mg,Si	Yes
	38	.06	.50						Yes
	39	.06	1.94						Yes
	40	.06	1.06						Yes
	41	.06	14.25	✓		✓			Yes
	42	.12	1.25						Yes
	43	.06	3.38						Yes
	44	.06	1.88						Yes
	45	.06	.88						Yes
	46	.12	3.00	✓		✓		Mg,Si	Yes
	47	.06	1.38						Yes
	48	.06	2.12						Yes

(continued)

TABLE D-2 (continued)

Grid Opening	Fiber Number	Fiber Dimension, µm		Electron Diffraction Pattern				X-ray Analysis Elements Present	Is Fiber Considered Asbestos
		Width	Length	Crystalline	Non Crystalline	Possible Asbestos	Ambiguous		
	49	.06	5.31						
	50	.12	1.75						Yes
	51	.06	3.25						Yes
	52	.03	2.19						Yes
	53	.06	1.62						Yes
	54	.06	1.25						Yes
	55	.06	8.75						Yes
	56	.12	8.00						Yes
	57	.44	1.62	✓		✓		Mg,Si,Mn,Fe	Yes
	58	.06	2.56						Yes
	59	.19	3.25						Yes
	60	.06	1.56						Yes
	61	.12	2.38						Yes
	62	.06	6.56						Yes
	63	.06	6.56						Yes
	64	.25	10.31						Yes
	65	.06	1.88						Yes
	66	.12	2.00						Yes
	67	.06	7.50						Yes
	68	.06	7.81						Yes
	69	.06	1.69						Yes
	70	.06	1.50						Yes
	71	.12	4.69						Yes
	72	.12	18.12						Yes
	73	.12	1.31						Yes
	74	.06	1.69						Yes
	75	.06	1.50						Yes
	76	.06	1.38						Yes
	77	.06	4.06						Yes
	78	.50	5.94						Yes
	79	.12	3.12						Yes
	80	.03	1.56						Yes
	81	.06	3.50						Yes
	82	.06	1.25						Yes
	83	.06	4.00						Yes
	84	.06	2.50						Yes
	85	.06	2.50						Yes
	86	.12	18.75						Yes
	87	.19	8.63						Yes
	88	.06	.62						Yes
	89	.06	3.25						Yes
	90	.06	2.19						Yes
	91	.06	10.00						Yes
	92	.06	.94						Yes
	93	.19	1.31						Yes
	94	.12	2.88						Yes
	95	.06	5.00						Yes
	96	.06	5.12						Yes

* Grid D3 ** Grid D5

Note: Fibers numbered 5, 24, 57 and 78 were calculated using the formula for magnesium - silicaces with iron based on their width measurements.

APPENDIX E

PARTICULATE TEST RESULTS FOR AIR CLASSIFIER DISCHARGE AND EPA MOBILE FILTER

(Mobile filter tests conducted by the Monsanto Company were under
the direction of Mr. John Snyder)

SUMMARY OF RESULTS

The overall filter bag efficiency was 99.95% by mass which was comparable and would be expected from fabric filter collection literature. (1) Fractional efficiency varied from 97.9% (2- to 3.3-µm size) to 99.98% (7- to 10-µm size) covering a particle size range from 1.1 to 10 µm.

The outlet size distribution showed that zero penetration was achieved for particles greater than 13.5 µm (when 80% of the particulate mass was in the 8.0 µm or smaller range).

The collected particulate matter emitted by the air classifier discharge was difficult to remove from the bags with the pulse bag cleaning mode used. The long-term effects of the inability to remove the linty, fluffy particulate collected are unknown at this time.

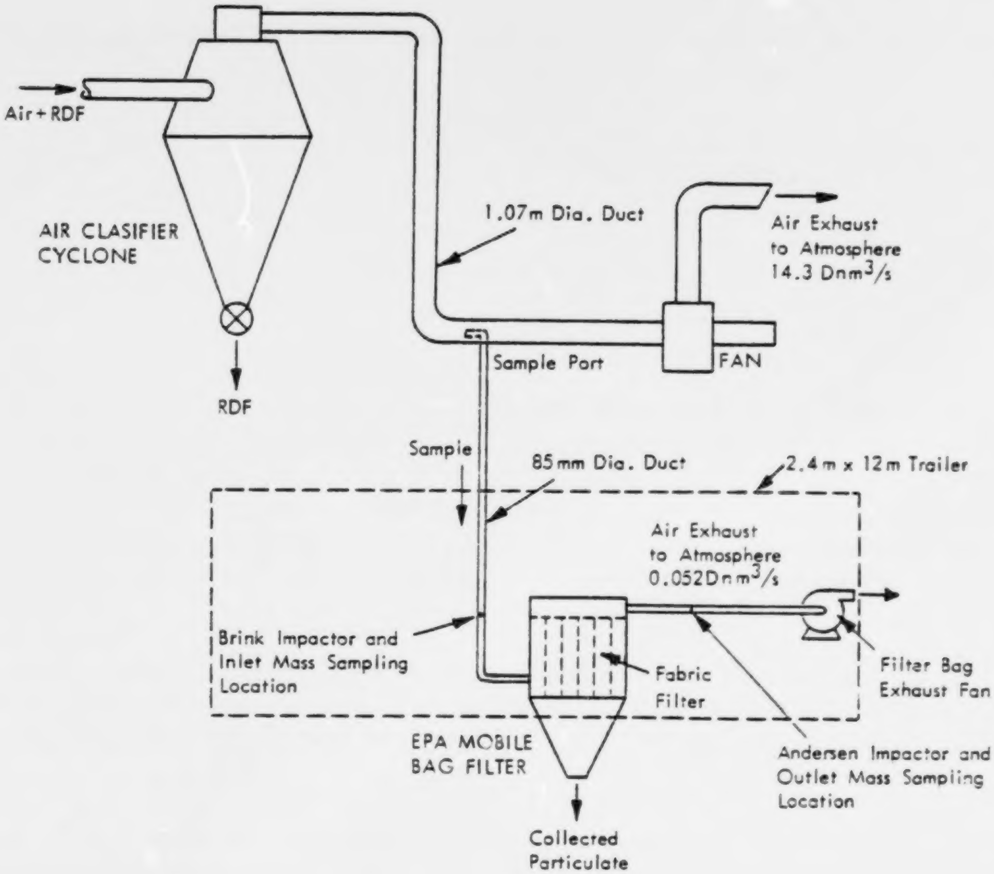
The assessment of the cleaning mode would be inappropriate with the limited data available from the 3-day test period.

The 0.019 m/sec (3.8 ft/min) air to cloth ratio was calculated from the 3-day average air flow rate (0.052 m^3/sec).

INTRODUCTION

Tests were conducted during the period of November 9 through 11, 1976, by Monsanto Research Corporation using the EPA Mobile Fabric Filter Unit for EPA's Industrial Environmental Research Laboratory as gas cleaning equipment. Figure E-1 shows the sampling locations and flow diagram for the filter bag. MRI sampled concurrently in the 1.07 m discharge duct using a Hi-Vol stack sampler identical to that used in previous tests. (2)

The baghouse, including controls and inlet and outlet sampling locations, is enclosed in a 2.4 x 12.2 m (8 x 40 ft) trailer. The slipstream probe in


Air + RDF
AIR CLASIFIER
CYCLONE
RDF
1.07m Dia. Duct
Air Exhaust
to Atmosphere
14.3 Dnm3/s
Sample Port
FAN
Sample
85mm Dia. Duct
2.4 m x 12 m Trailer
Air Exhaust
to Atmosphere
0.052Dnm3/s
Brink Impactor and
Inlet Mass Sampling
Location
Fabric
Filter
Filter Bag
Exhaust Fan
EPA MOBILE
BAG FILTER
Andersen Impactor and
Outlet Mass Sampling
Location
Collected
Particulate

Operation: EPA bag filter draws a portion of the Air Classifier Cyclone exhaust from the 1.07m dia. duct. This air sample is passed continuously through the fabric filter to determine filter filter efficiency.

Figure E-1. Flow diagram of EPA mobile bag filter.

the air classifier cyclone exhaust was located at a point of average velocity to assure a representative baghouse sample.

The EPA mobile filter bag cleaning system was a pulse jet system using a 552 kPa compressed air pulse at 1/2-min intervals with 0.1 sec pulse durations

Five dacron polyester felt bags were used with the following specifications:

Manufacturer: Globe Albany Corporation - Style 136 B
Weight: 611 g/m^2 (18 oz/yd^2)
Diameter: 11.4 cm (4.5 in.)
Length: 122 cm (48 in.)
Permeability: 10.7 m/min at 0.125 kPA (35 cfm/ft^2 at 0.5 in. W.C.)

TEST METHODOLOGY

Particulate tests were conducted using Gelman glass filters for inlet and outlet total mass measurements and a Brink impactor and an Andersen impactor to determine particle size distribution for the inlet and outlet, respectively. Isokinetic sampling was maintained for the particulate mass samples and both Andersen particle size distribution samples. Glass fiber substrates were used as the collection medium for the impactor collection stages.

Due to low particulate concentrations in the baghouse outlet, it was impossible to accumulate enough particulate in 1 day for accurate mass determination. Therefore, an outlet value accumulated over 3 days of sampling was used.

All bag filter inlet mass samples were considered invalid due to problems with nozzle plugging. Therefore, the inlet particulate concentration was derived from the 3-day accumulation of the dust collected in the baghouse hopper and the sample accumulated for 3 days at the outlet. Even after 3 days, weight gains on the Andersen substrates were marginally useable.

TEST RESULTS

Following in Table E-1 is the data tabulation from the St. Louis particulate tests during November 9 through 11, 1976, for the EPA mobile filter.

DATA COMPARISON

The Monsanto data compares favorably with the data collected by MRI at St. Louis in November 1974, and July 1975, (2) and the November 1976 samples, taken at the air classifier discharge. All values calculated for particulate

TABLE E-1. EPA MOBILE BAG FILTER

	Inlet	Outlet
Particulate matter concentration (mg/dNm^3)	300	0.154
Emission rate (kg/hr)	0.056	2.87×10^{-5}
Gas flow rate $\frac{dNm^3}{sec}$	0.052	0.052

concentrations and particulate emissions in the air classifier discharge (baghouse inlet for Monsanto tests) were within the range of data collected by MRI. Table E-2 compares the Monsanto data with all the MRI particulate data. The average inlet concentration (0.300 g/Nm^3) was very close to the MRI value for the three air classifier discharge tests conducted during the same period as the Monsanto tests.

BAG FILTER EFFICIENCY

The outlet size distribution, Figure E-2, shows that about 80% of the mass was less than 8.0 μm. Assuming the air classifier discharge (bag filter inlet) size distribution had remained the same, the inlet particle distribution accounted for less than 10% of the mass below 8.0 μm. The inlet size distribution data were taken from previous MRI test results. (2)

Using this inlet distribution a bimodal fractional efficiency curve was developed as shown in Figure E-3. The fractional efficiency graph covers a particle size range of 1.1 to 10 μm. The efficiencies ranged from 97.9 to 99.98% as shown below:

Particle size (μm)	Removal efficiency (%)
1.1	99.64
1.1-2	98.83
2-3.3	97.90
3.3-7.0	99.94
7-10	99.98

TABLE E-2. COMPARISON OF MRI AND MONSANTO PARTICULATE DATA

MRI data air classifier discharge

	Averages for previous tests (2)	Date for tests in November 1976		
		11/9	11/10	11/11
Particulate conc. (g/dNm^3)	0.57	0.26	0.36	0.27
Particulate emissions (kg/hr)	22.84	14.2	17.8	14.9
Gas flow rate (air) (Nm^3/sec)	13.34	15.2	13.7	15.3

Monsanto data (November 9-11, 1976)

Baghouse

Particle conc. (g/Nm^3)

Baghouse inlet: 0.300 (compares to air classifier discharge above 0.26 to 0.36 g/dNm^3)

Baghouse outlet: 0.000154

Overall baghouse efficiency: 99.95%

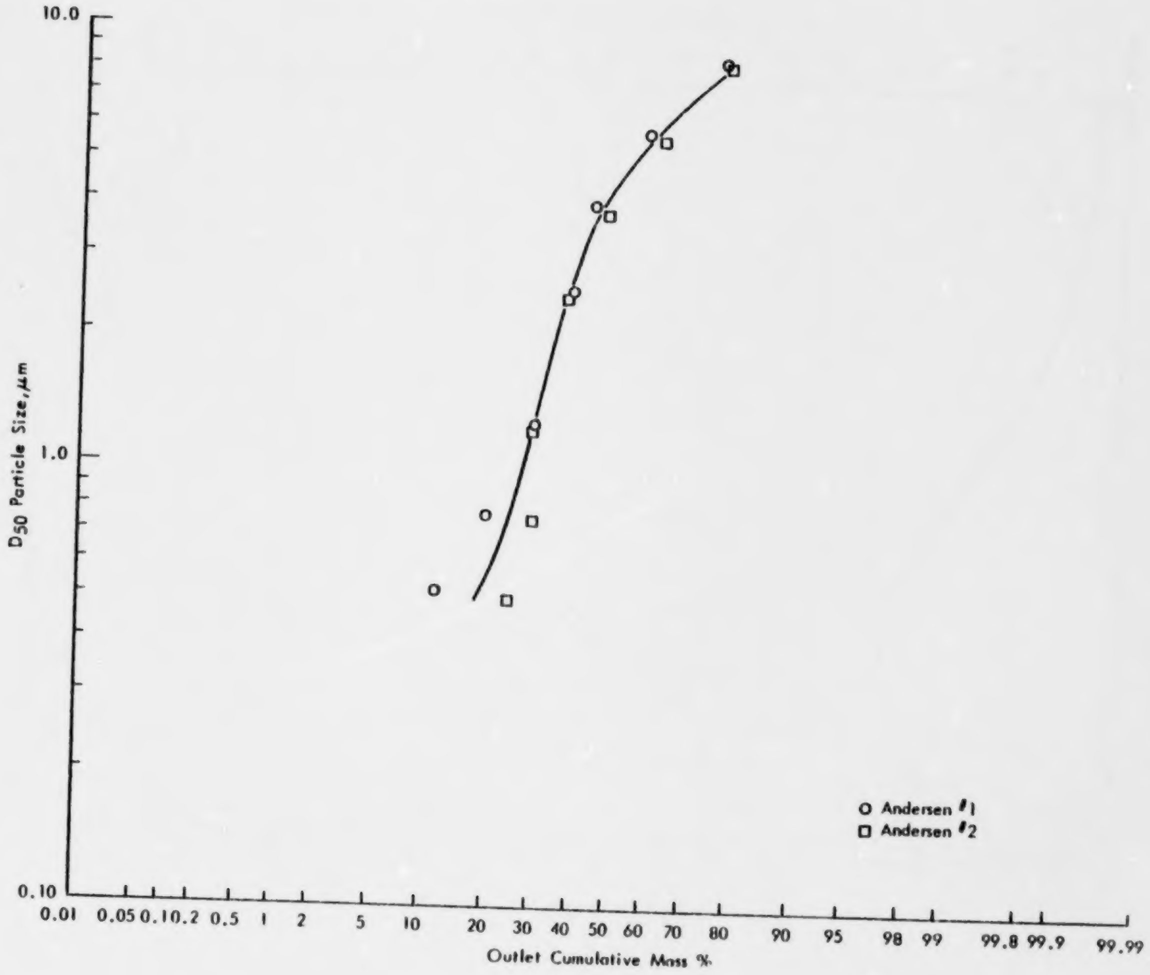


Figure E-2. Baghouse outlet cumulative size distribution.

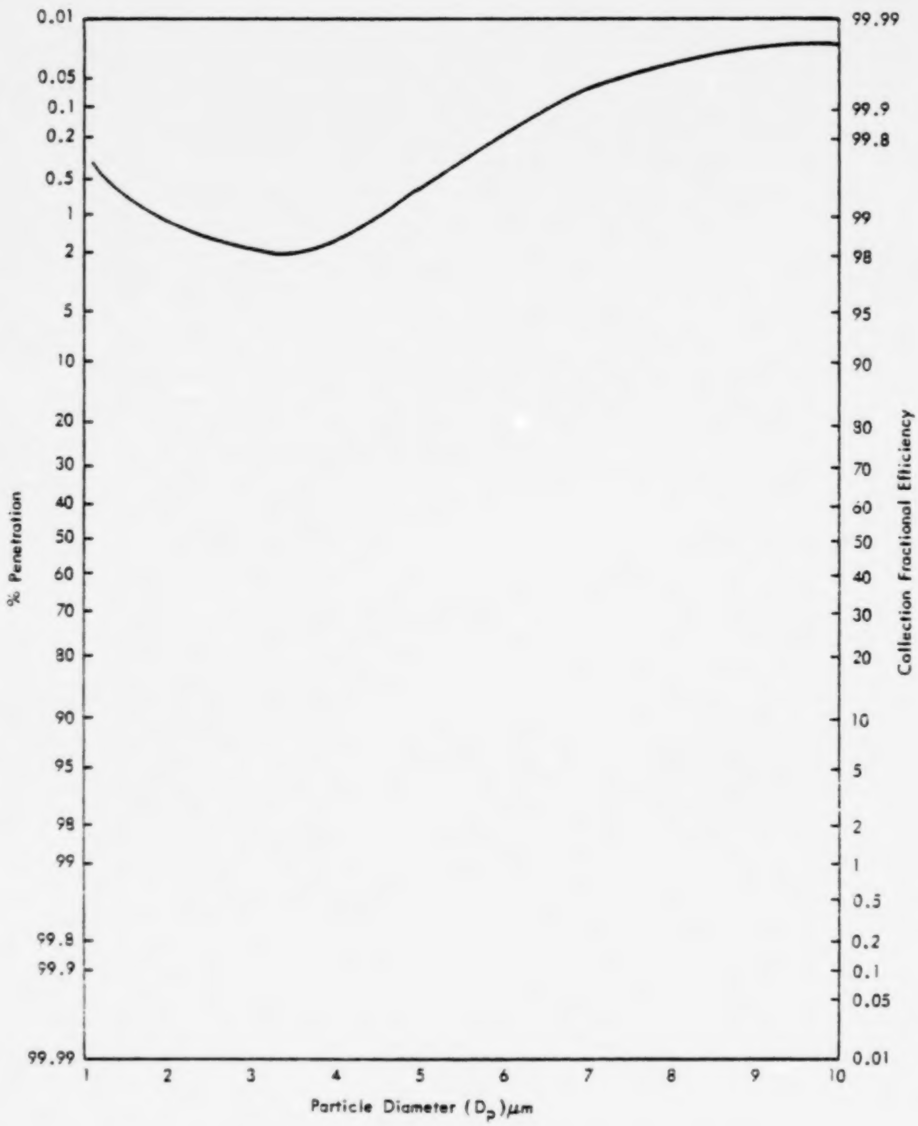


Figure E-3. Fractional efficiency curve.

REFERENCES FOR APPENDIX E

1. An average overall collection efficiency of 99.7% for a baghouse was taken from the following reference: Compilation of Air Pollutant Emission Factors. Revised. Environmental Protection Agency, Research Triangle Park, North Carolina, February 1972.

2. Fiscus, D. E., P. G. Gorman, M. P. Schrag, and L. J. Shannon. St. Louis Demonstration Final Report: Refuse Processing Plant Equipment, Facilities and Environmental Evaluations. Prepared for U.S. Environmental Protection Agency, IERL, OSWMP, SHWRL, EPA Contract Nos. 68-02-1324 and 68-02-1871, Midwest Research Institute, April 15, 1977.

APPENDIX F

TRACE ELEMENT ANALYSIS PROCEDURES AND ANALYTICAL RESULTS

EXPERIMENTAL

Ambient air samples and air classifier discharge samples were collected on 0.20 x 0.25 m high volume filters. One-fourth of each filter was analyzed for metals by atomic absorption spectrophotometry. A single digestion method had to be chosen for the ambient air filter samples because of low particulate loading. The air classifier discharge samples had sufficient material for several digestions. A HNO_3-$HClO_4$-H_2SO_4 digestion was chosen to solubilize organic and inorganic refuse material from the filter without dissolving the filter. All metals were analyzed from this acid matrix except barium, which precipitated as $BaSO_4$. The pyrolytic carbon rods (or furnace) could not tolerate $HClO_4$-H_2SO_4 mixture; therefore, the $HClO_4$ was driven off.

A second digest (HNO_3-$HClO_4$) was chosen to obtain barium from the air classifier inlet samples. This digestion method could not be used on the outlet samples because they had been consumed by the first digestion.

Instrumentation

A Varian AA6 atomic absorption spectrophotometer with background correction was used for flame (Ba, Cr, Cu, Ag, and Zn), hydride (As, Se, and Sb) and cold vapor (Hg) analysis. Pb analyses were performed using the Varian AA6 equipped with a Model 63 carbon rod atomizer. A Perkin-Elmer 306 atomic absorption spectrophotometer equipped with background correction was used for flame analysis of Pb. An HGA 2100 graphite furnace in conjunction with the Perkin-Elmer Model 306 was used for the analysis of Be and Cd.

Instrumental Parameters

Parameters for the various metal analysis techniques used are listed in Table F-1.

TABLE F-1. SUMMARY OF PARAMETERS FOR METAL ANALYSIS

I. Technique: Flame atomic absorption

A. Instrument: Varian AA6

Instrumental parameters

Element	λ (m x 10^{-7})	Flame gases		
		C_2H_2 (ℓ/min)	Air (ℓ/min)	N_2O (ℓ/min)
Ba	3.535[a]	4.5	-	8.4
Cr	3.579[a]	4.5	-	8.4
Cu	3.248[a]	1.2	10.0	-
Ag	3.281	1.2	10.0	-
Zn	2.138	1.2	10.0	-

B. Instrument: Perkin-Elmer 306

Instrumental parameters

Element	λ (m x 10^{-7})	Flame gases	
		C_2H_2 (ℓ/min)	Air (ℓ/min)
Pb	2.170	2.8	26.6

C. Instrument: Varian AA6 with hydride generator

Instrumental parameters

Element	λ (m x 10^{-7})	Flame gases		Sweep gas
		H_2 (ℓ/min)	N_2 (ℓ/min)	N_2 (ℓ/min)
Sb	2.176	2.5	10.0	1.0
As	1.937	2.5	10.0	1.0
Se	1.960	2.5	10.0	1.0

(continued)

TABLE F-1 (continued)

II. Technique: Flameless atomic absorption

A. Instrument: Varian AA6 with CRA 63 carbon rod atomizer

	Instrumental parameters					
	λ	H_2	N_2	Atomization conditions		
Element	(m x 10^{-7})	(ℓ/min)	(ℓ/min)	Dry	Ash	Atomize
Pb	2.170	0	4.4	4.5 v/25 sec	4 v/20 sec	6 v/3 sec

B. Instrument: Perkin-Elmer 306 with HGA 2100 graphite furnace

	Instrumental parameters					
	λ	Argon (flow-meter		Atomization conditions		
Element	(m x 10^{-7})	setting)	Mode	Dry	Ash	Atomize
Be	2.349	30	Normal	125°C/ 35 sec	1100°C/ 20 sec	≈3000°C/ 15 sec
Cd	2.288	30	Normal	120°C/ 30 sec	310°C/ 10 sec	2600°C/ 4 sec

C. Instrument: Varian AA6 with cold vapor mercury absorption cell

	Instrumental parameters	
Element	λ (m x 10^{-7})	Sweep gas Air (ℓ/min)
Hg	2.537	2.5

---

a/ Not background-corrected, but this is not expected to cause any error.

Apparatus

Metal hydrides of As, Sb, and Se were generated in a reaction vessel having an inlet for the sweep gas (N_2), a septum for the injection of sodium borohydride solution, and an outlet arm with a balloon for the collection of the hydride. After a 10-sec reaction time, the gaseous hydride was swept through an outlet tube into the flame.

The cold vapor apparatus used to generate elemental mercury vapor consisted of a reaction vessel with a fritted glass inlet for the sweep gas (air) and an outlet leading into a closed cell placed in the optical path.

Reagents

Ultrapure HCl, H_2SO_4, and $HClO_4$ were used for all sample digestions.

Metal hydrides were generated using reagent grade HCl, NaI and a reducing solution of 20% (w/v) $NaBH_4$ (reagent grade, 98%) in 10% (w/v) NaOH (reagent grade).

Atomic mercury vapor was generated using a 10% (w/v) $SnCl_2$ in 10% (w/v) HCl solution prepared from reagent grade materials.

Working standards were prepared from commercial 1,000 ppm stock solutions diluted in a suitable acid matrix of deionized water and H_2SO_4.

Sample Preparation Procedures

Ambient filters, blank filters, and weighed portions of the air classifier discharge sample without the filter were shredded into precleaned (boiled in HNO_3 acid) beakers, and 20 ml HNO_3 and 10 ml H_2SO_4 were added to each sample. The acidified samples were refluxed in covered beakers on a hot plate until the HNO_3 was exhausted. During the reflux period, the samples were occasionally stirred with individual glass rods to ensure adequate contact of the particulate with the acids. After cooling, 10 ml HNO_3 and 5 ml $HClO_4$ were added and the samples heated until all HNO_3 had been driven off. At this point the $HClO_4$ had consumed all remaining organic material and was fumed off leaving $<$ 10 ml H_2SO_4. The samples were then diluted to 25 ml volume with deionized water.

The digestion of the air classifier discharge samples for barium was similar to the above procedure except H_2SO_4 was omitted. The weighed portions of the inlet sample were digested with 30 ml HNO_3, evaporated to 10 ml, cooled, and 20 ml $HClO_4$ added. The samples were brought to the fuming stage of $HClO_4$, at which point a white precipitate was formed. The samples were centrifuged, the supernatant decanted and brought to a 50-ml volume with deionized water.

The precipitate was analyzed by X-ray emission and appeared to be a tin compound.

Analysis Procedures

Samples were nebulized directly for flame analyses. Samples and standards for barium analysis were fortified with 2,000 ppm potassium to suppress ionization in the flame.

For hydride analysis, an aliquot was added to 20 ml of 50% (v/v) HCl and pretreated (for antimony only) with 10 ml of 10% (w/v) NaI. The reaction jar was sealed, purged, and the system sealed from the flame by a four-way valve. Two milliliters of the reducing solution was injected with a syringe while the sample was magnetically stirred with a stirring bar. The hydride was collected in a balloon reservoir for a reaction time of 10 sec. The trapped hydride was then swept into the flame using a nitrogen stream.

For mercury analysis, an aliquot was placed in a reaction vessel, then brought to a 60-ml volume with deionized water. Two milliliters of 10% (w/v) $SnCl$ in 10% (v/v) HCl was added and the vessel was sealed. Air was bubbled into the solution through a fritted glass inlet and the vapor swept into the closed absorption cell.

ANALYTICAL RESULTS

The results for the samples are listed in Table F-2. Ambient sample results have been calculated to obtain the total weight (μg) collected on the entire filter. Barium was determined for the air classifier discharge samples only. The sample results have not been corrected for the blank filter values, but these values are listed in the table. In some cases (Zn and Cd) blank values showed levels at or above the detection limit (signal equal to twice the noise level).

Relatively high detection limits for the hydrides and mercury resulted from low sample volumes available for analysis after digesting the samples for flame analysis.

The contamination of silver in consecutive bottles of the ultrapure H_2SO_4 used in the digest of ambient samples and the standards was found to be over 6,000 times higher than the minimum listed in the certificate of analysis sent by the manufacturer. The analysis of silver has been deleted because of extremely high values obtained on the NBS Reference Materials. These high values were the result of Ag contamination of the H_2SO_4. Chromium concentrations in the ultrapure HNO_3 and $HClO_4$ were at levels five times higher than certified values. The Cr levels in the acid were not significant compared to Cr levels

TABLE F-2. ELEMENTAL ANALYSIS RESULTS

Sample	Concentration in particulate (µg/gram)											Quantity of air sampled through filter (M^3)
	Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Se	Zn	Ba	
Air Classifier Discharge:												
Air classifier 1-3	< 5	22	0.22	1.9	83	74	430	0.93	< 30	680	130	-
Air classifier 2-3	4.2	9.1	0.18	7	78	60	320	0.35	< 28	520	94	-
Air classifier 3-3	7.7	5.7	0.23	4.6	97	100	400	< 0.4	< 25	740	130	-
Ambient:	Total micrograms (µg) collected on 8 x 10 high volume filter											
Incinerator												
049 Upwind	< 8	< 3	0.15	1.0	< 20	48	380	< 0.8	< 16	170	a/	408
051 Downwind-primary	< 8	< 3	0.076	1.4	< 20	40	1,000	< 0.8	< 16	130	a/	408
053 Downtown	< 8	< 3	< 0.08	0.6	< 20	20	380	< 0.4	< 16	52	a/	393
Process Plant												
082 Upwind	< 8	< 3	0.072	0.8	< 20	180	280	< 0.8	< 16	120	a/	405
084 Downwind-primary	< 12	6	0.23	3	68	160	920	< 3	< 80	800	a/	408
089 Downtown	< 8	< 3	< 0.04	0.2	< 20	40	340	< 1	< 16	28	a/	408
Wastewater Treatment Plant												
115 Upwind	< 8	< 3	0.024	1.0	< 20	48	240	< 2	< 16	44	a/	377
117 Downwind-primary	< 8	< 3	0.052	1.2	< 20	92	400	< 0.8	< 16	52	a/	409
Waste Transfer Station												
110 Upwind	< 8	< 3	0.056	1.0	68	52	< 200	< 2	< 16	96	a/	401
202 Downwind-primary	< 8	3.6	0.092	1.0	60	76	640	< 0.8	< 16	84	a/	415
Sanitary Landfill												
216 Upwind	< 8	< 3	< 0.03	0.6	< 20	30	480	a/	< 16	24	a/	408
218 Downwind-primary	< 8	< 3	0.08	< 0.2	< 20	20	240	< 0.8	< 16	36	a/	408

(continued)

TABLE F-2 (continued)

Sample	Total micrograms (µg) collected on 8 x 10 high volume filter											Quantity of air sampled through filter (M^3)
	Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Se	Zn	Ba	
Blanks												
054 Blank (11/03/76)	< 8	< 3	< 0.08	< 0.2	< 20	< 12	< 200	< 0.4	< 16	8	a/	-
100 Blank (11/10/76)	< 8	< 12	< 0.04	< 0.2	< 20	< 12	< 200	< 0.4	< 16	< 8	a/	-
204 Blank (11/24/76)	< 8	< 3	< 0.04	0.4	< 20	< 12	< 200	< 0.8	< 16	< 8	a/	-

a/ Insufficient sample quantity.

in the air classifier discharge samples, but did restrict detection limits for ambient samples.

Quality Assurance

The accuracy and precision of the results were determined by analyzing NBS Reference Materials and an acid blank fortified with As, Sb, Se, and Hg.

Duplicate samples of the NBS Reference Materials were analyzed and the results are presented in Table F-3, along with the certified NBS values and values obtained by J. M. Ondov. (1) Recoveries from the fortified sample were 87% for Sb, ranged from 60 to 160% (four analyses) for As, 55 to 68% for Se, and 44% for Hg. The loss of mercury was due to the heating of the sample when $HClO_4$ was driven off.

Barium results for one of the inlet samples were verified by the standard addition method.

REFERENCES FOR APPENDIX F

1. Ondov, J. M. et al. Analytical Chemistry, 47:1107 (1975)

TABLE F-3. ELEMENTAL CONCENTRATIONS OF STANDARD REFERENCE MATERIALS

Reference material[a/]	Elemental concentration (µg/g, ppm) Sb	As	Be	Cd	Cr	Cu	Pb	Se	Zn
NBS Orchard leaves - 1	1.3	17, 20	< 10	< 0.3	< 6	15	< 8	< 0.3	25
2	1.2	20, 25, 18, 20	< 10	< 0.3	< 6	15	< 8	< 0.4	25
NBS Values	-	14 ± 2	-	0.11 ± 0.002	(2.3)	12 ± 1	45 ± 3	0.08 ± 0.01	25 ± 3
NBS Coal - 1	-	13	2.2	0.25	25	20	-	< 20	30
2	-	10	2.0	0.25	35	20	-	< 20	35
NBS Values	-	5.9 ± 0.6	(1.5)	0.19 ± 0.03	20.2 ± 0.5	18 ± 2	30 ± 9	2.9 ± 0.3	37 ± 4
Reference b values (1)	3.9 ± 1.3	6.5 ± 1.4	-	-	19.7 ± 0.9	-	-	3.4 ± 0.2	30 ± 10
NBS Fly ash - 1	1.8	59	6.2	1.0	100	75	< 37	6.8	100
2	1.6	79	5.7	1.3	100	70	< 37	4.5	95
NBS Values	-	61 ± 6	(12)	1.45 ± 0.06	131 ± 2	128 ± 5	70 ± 4	9.4 ± 0.5	210 ± 20
Reference b values (1)	6.9 ± 0.6	58 ± 4	-	-	127 ± 6	-	75 ± 5	10.2 ± 1.4	216 ± 25

a/ ( ) = approximate NBS values.

APPENDIX G

TABULATION OF SAMPLING DATA FOR HI-VOLS AND METEOROLOGICAL DATA

TABLE G-1. WEEK NO. 1--INCINERATOR (Hi-Vols)

	Test day	Date	Sample No.	Sample rate (ℓ/sec)	Sample time (min)	Sample volume (m^3)	Average meteorological data			
							Dry bulb temp. (°C)	Relative humidity (%)	Wind direction	Wind velocity (m/sec)
Upwind	0	11/1/76	028	19	114	129	15	38	S	1.9
Scale rm	0	11/1/76	025	19	158	179	15	38	S	1.9
Crane	0	11/1/76	027	19	162	183	15	38	S	1.9
Tip floor	0	11/1/76	026	19	158	179	15	38	S	1.9
Upwind	1	11/2/76	039	19	367	415	19	50	SW	3.6
Dw-west	1	11/2/76	038	19	362	410	19	50	SW	3.6
Dw-prim	1	11/2/76	037	19	354	401	19	50	SW	3.6
Dw-east	1	11/2/76	036	19	352	398	19	50	SW	3.6
Scale rm	1	11/2/76	041	19	373	422	17	55		
Crane	1	11/2/76	040	19	370	419	17	55		
Tip floor	1	11/2/76	042	19	374	423	17	55		
Downtown	1	11/2/76	034	19	347	393	13	55	SW	3.6
Packer trk -										
left	1	11/2/76	030	19	235	266	19	50	SW	4.0
right	1	11/2/76	031	19	235	266	19	50	SW	4.0
Upwind	2	11/3/76	049	19	360	408	12	27	WNW	5.4
Dw-west	2	11/3/76	050	19	360	408	12	27	WNW	5.4
Dw-prim	2	11/3/76	051	19	360	408	12	27	WNW	5.4
Dw-south	2	11/3/76	052	19	360	408	12	27	WNW	5.4
Scale rm	2	11/3/76	047	19	360	408	14	18		
Crane	2	11/3/76	048	19	360	408	15	21		
Tip floor	2	11/3/76	046	19	360	408	14	18		
Downtown	2	11/3/76	053	19	347	393	12	27	WNW	5.4
Packer trk										
left	2	11/3/76	032	19	220	249	11	34	WNW	3.6
right	2	11/3/76	033	19	220	249	11	34	WNW	3.6
Upwind	3	11/4/76	056	19	353	400	3.8	59	NNW	4.0
Dw-north	3	11/4/76	057	19	376	426	3.8	59	NNW	4.0
Dw-prim	3	11/4/76	058	19	369	418	3.8	59	NNW	4.0
Dw-south	3	11/4/76	064	19	361	409	3.8	59	NNW	4.0
Scale rm	3	11/4/76	063	19	395	447	2.2	18		
Crane	3	11/4/76	061	19	386	437	6.0	40		
Tip floor	3	11/4/76	062	19	388	439	6.0	38		
Downtown	3	11/4/76	065	19	380	430	3.8	59	NNW	4.0
Packer trk										
left	3	11/4/76	041	19	255	289	3.3	50	NNW	4.5
right	3	11/4/76	045	19	255	289	3.3	50	NNW	4.5

TABLE G-2. WEEK NO. 2--RDF PLANT (Hi-Vols)

	Test day	Date	Sample No.	Sample rate (ℓ/sec)	Sample time (min)	Sample volume (m^3)	Average meteorological data			
							Dry bulb temp. (°C)	Relative humidity (%)	Wind direction	Wind velocity (m/sec)
Uw-south	0	11/8/76	059	19	357	404	5.5	55	SSW	3.6
Dw-west	0	11/8/76	060	19	366	414	5.5	55	SSW	3.6
Dw-prim	0	11/8/76	066	19	364	412	5.5	55	SSW	3.6
Dw-east	0	11/8/76	067	19	365	413	5.5	55	SSW	3.6
Control rm	0	11/8/76	076	19	382	432				
Pack sta	0	11/8/76	075	19	387	438				
Tip floor	0	11/8/76	074	19	397	449				
Downtown	0	11/8/76	068	19	286	324	5.5	55	SSW	3.6
Uw-RR trk (west)	1	11/9/76	072	19	355	402	15	43	W	4.5
Dw-north	1	11/9/76	071	19	356	403	15	43	W	4.5
Dw-prim	1	11/9/76	070	19	355	402	15	43	W	4.5
Dw-south	1	11/9/76	069	19	350	396	15	43	W	4.5
Control rm	1	11/9/76	080	19	360	408	22	27		
Pack sta	1	11/9/76	079	19	360	408	16	32		
Tip floor	1	11/9/76	078	19	365	413	14	37		
Downtown	1	11/9/76	073	19	363	411	15	43	W	4.5
Uw-RR trk (west)	2	11/10/76	082	19	358	405	9.4	37	NW	4.0
Dw-north	2	11/10/76	083	19	360	408	9.4	37	NW	4.0
Dw-prim	2	11/10/76	084	19	360	408	9.4	37	NW	4.0
Dw-south	2	11/10/76	085	19	360	408	9.4	37	NW	4.0
Control rm	2	11/10/76	088	19	360	408	18	23		
Pack sta	2	11/10/76	087	19	360	408	6.6	42		
Tip floor	2	11/10/76	086	19	360	408	9.4	37		
Downtown	2	11/10/76	089	19	360	408	9.4	37	NW	4.0
Uw-north	3	11/11/76	091	19	364	412	2.2	59	N	3.6
Dw-north	3	11/11/76	094	19	363	411	2.2	59	N	3.6
Dw-prim	3	11/11/76	093	19	363	411	2.2	59	N	3.6
Dw-south	3	11/11/76	092	19	363	411	2.2	59	N	3.6
Control rm	3	11/11/76	097	19	360	408				
Pack sta	3	11/11/76	096	19	360	408				
Tip floor	3	11/11/76	095	19	363	411	3.3	53		
Downtown	3	11/11/76	099	19	360	408	2.2	59	N	3.6

TABLE G-3. WEEK NO. 3--WASTEWATER TREATMENT PLANT (Hi-Vols)

							Average meteorological data			
	Test day	Date	Sample No.	Sample rate (ℓ/sec)	Sample time (min)	Sample volume (m^3)	Dry bulb temp. (°C)	Relative humidity (%)	Wind direction	Wind velocity (m/sec)
Upwind	1	11/15/76	100	19	254	288	8.3	33	SE	1.3
Dw-north	1	11/15/76	101	19	216	245	8.3	33	SE	1.3
Dw-prim	1	11/15/76	102	19	260	294	8.3	33	SE	1.3
Dw-south	1	11/15/76	103	19	222	251	8.3	33	SE	1.3
Prim set	1	11/15/76	106	19	207	234				
Aeration	1	11/15/76	107	19	192	217				
Pressrm	1	11/15/76	104	19	224	254	15	29		
Pressrm bsmt	1	11/15/76	105	19	231	261	15	29		
Upwind	2	11/16/76	115	19	333	377	7.2	58	SW	0.9
Dw-west	2	11/16/76	118	19	360	408	7.2	58	SW	0.9
Dw-prim	2	11/16/76	117	19	361	409	7.2	58	SW	0.9
Dw-east	2	11/16/76	116	19	362	410	7.2	58	SW	0.9
Prim set	2	11/16/76	113	19	360	408				
Aeration	2	11/16/76	114	19	361	409				
Pressrm	2	11/16/76	111	19	360	408	15	48		
Pressrm bsmt	2	11/16/76	112	19	364	412	18	40		
Upwind	3	11/17/76	125	19	361	409	11	46	SW	4.9
Dw-west	3	11/17/76	126	19	361	409	11	46	SW	4.9
Dw-prim	3	11/17/76	127	19	361	409	11	46	SW	4.9
Dw-east	3	11/17/76	128	19	360	408	11	46	SW	4.9
Prim set	3	11/17/76	119	19	360	408				
Aeration	3	11/17/76	120	19	360	408				
Pressrm	3	11/17/76	121	19	361	409	18	35		
Pressrm bsmt	3	11/17/76	122	19	360	408	15	47		
Upwind	4	11/18/76	144	19	350	396	18	36	SSW	2.7
Dw-west	4	11/18/76	143	19	360	408	18	36	SSW	2.7
Dw-prim	4	11/18/76	142	19	350	396	18	36	SSW	2.7
Dw-east	4	11/18/76	145	19	360	408	18	36	SSW	2.7
Prim set	4	11/18/76	138	19	360	408				
Aeration	4	11/18/76	139	19	360	408				
Pressrm	4	11/18/76	140	19	360	408				
Pressrm bsmt	4	11/18/76	141	19	360	408				

TABLE G-4. WEEK NO. 4--WASTE TRANSFER STATION (Hi-Vols)

	Test day	Date	Sample No.	Sample rate (ℓ/sec)	Sample time (min)	Sample volume (m^3)	Average meteorological data: Dry bulb temp. (°C)	Average meteorological data: Relative humidity (%)	Average meteorological data: Wind direction	Average meteorological data: Wind velocity (m/sec)
Upwind	1	11/22/76	131	19	361	409	3.3	42	WNW	2.2
Dw-north	1	11/22/76	130	19	367	415	3.3	42	WNW	2.2
Dw-prim	1	11/22/76	129	19	360	408	3.3	42	WNW	2.2
Dw-south	1	11/22/76	123	19	360	408	3.3	42	WNW	2.2
Trk ramp	1	11/22/76	146	19	361	409	5.0	47	WNW	2.2
Tip floor										
east	1	11/22/76	135	19	360	408	3.8	34	WNW	2.2
north	1	11/22/76	136	19	360	408	4.4	46	WNW	2.2
Upwind	2	11/23/76	010	19	351	397	2.2	72	E	2.2
Dw-west	2	11/23/76	009	19	360	408	2.2	72	E	2.2
Dw-prim	2	11/23/76	001	19	360	408	2.2	72	E	2.2
Dw-east	2	11/23/76	149	19	361	409	2.2	72	E	2.2
Trk ramp	2	11/23/76	133	19	360	408	5.0	54	E	2.2
Tip floor										
east	2	11/23/76	134	19	367	415	5.5	70	E	2.2
north	2	11/23/76	132	19	368	417	1.6	82	E	2.2
Upwind	3	11/24/76	110	19	354	401	13	40	SW	2.2
Dw-west	3	11/24/76	203	19	362	410	13	40	SW	2.2
Dw-prim	3	11/24/76	202	19	367	415	13	40	SW	2.2
Dw-east	3	11/24/76	201	19	241	273	13	40	SW	2.2
Trk ramp	3	11/24/76	150	19	217	246	12	42	SW	2.2
Tip floor										
east	3	11/24/76	014	19	360	408	10	43	SW	2.2
north	3	11/24/76	015	19	240	272	16	35	SW	2.2

TABLE G-5. WEEK NO. 5--SANITARY LANDFILL (Hi-Vols)

	Test day	Date	Sample No.	Sample rate (ℓ/sec)	Sample time (min)	Sample volume (m^3)	Average meteorological data			
							Dry bulb temp. (°C)	Relative humidity (%)	Wind direction	Wind velocity (m/sec)
Upwind	1	11/29/76	209	19	360	408	-4.4	72	Data not recorded	Data not recorded
Dw-east	1	11/29/76	208	19	360	408	-1.6	66		
Dw-prim	1	11/29/76	207	19	360	408	-1.6	66		
Dw-west	1	11/29/76	206	19	360	408	-1.6	66		
Working face										
east	1	11/29/76	205	19	315	357	-4.4	72		
west	1	11/29/76	214	19	321	364	-3.8	61		
Scale-off	1	11/29/76	215	19	360	408	-4.4	72		
Upwind	2	11/30/76	216	19	360	408	-1.6	66	S	3.1
Dw-east	2	11/30/76	219	19	360	408	-1.6	66	S	3.1
Dw-prim	2	11/30/76	218	19	360	408	-1.6	66	S	3.1
Dw-west	2	11/30/76	217	19	360	408	-1.6	66	S	3.1
Working face										
east	2	11/30/76	213	19	360	408	-1.6	66	S	3.1
west	2	11/30/76	212	19	360	408	-1.6	66	S	3.1
Scale-off	2	11/30/76	211	19	360	408	-1.6	66	S	3.1
Upwind	3	12/1/76	225	19	365	413	-2.7	53	NW	2.7
Dw-east	3	12/1/76	224	19	340	385	-2.7	53	NW	2.7
Dw-prim	3	12/1/76	223	19	345	391	-2.7	53	NW	2.7
Dw-west	3	12/1/76	226	19	362	410	-2.7	53	NW	2.7
Working face										
east	3	12/1/76	222	19	360	408	-2.7	53	NW	2.7
west	3	12/1/76	221	19	360	408	-2.7	53	NW	2.7
Scale-off	3	12/1/76	220	19	360	408	-2.7	53	NW	2.7

APPENDIX H

TABULATION OF HI-VOL BACTERIA RESULTS AND MORPHOLOGICAL CHARACTERISTICS OF ISOLATES FROM HI-VOL AND ANDERSEN SAMPLES

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TABLE H-1. INCINERATOR (Hi-Vol)

	Test day	Date	Sample No.	Bacteria count/m^3 (MPN): Total plate count	Total coliform	Fecal coliform	Fecal streptococci	Filter slurry pH	Morphological characteristics of isolates: High-volume sampler	Andersen impactor sampler[a/]
Upwind	0	11/1/76	028	< 1,510	< 0.061	< 0.061	5.75	0		
Scale rm	0	11/1/76	025	34,800	1.64	0.676	261	0	G+rods, G-rods Ⓢ[b/]	
Crane	0	11/1/76	027	59,700	4.86	1.60	< 2.13	0	G+rods, G-rods Ⓢ	
Tip floor	0	11/1/76	026	59,900	18.6	4.86	261	0	G+rods, G-rods, G-cocci	
Upwind	1	11/2/76	039	470	0.019	0.019	0.960	7.4		
Dw-west	1	11/2/76	038	1,900	1.18	< 0.020	< 0.952	7.9		
Dw-prim	1	11/2/76	037	2,910	0.768	0.224	1.95	7.2	G+rods, G-rods Ⓢ	G+rods, G-rods, G-cocci
Dw-east	1	11/2/76	036	1,960	0.225	0.049	1.96	7.6	G+rods, G-rods Ⓢ	
Scale rm	1	11/2/76	041	47,700	0.416	0.416	166	9.9		
Crane	1	11/2/76	040	109,000	3.30	3.30	363	9.2	G+rods, G-rods, G-cocci, high mold count	Heavy mold count
Tip floor	1	11/2/76	042	239,000	1.18	1.18	230	11.0		
Downtown	1	11/2/76	034	< 497	0.486	0.328	1.99	8.5		
Packer trk-left	1	11/2/76	030	106,000	> 352	> 352	420	8.3	G+rods, G-rods Ⓢ	
Packer trk-right	1	11/2/76	031	109,000	> 352	> 352	792	8.4		
Upwind	2	11/3/76	049	6,045	0.191	0.020	7.64	7.8		
Dw-west	2	11/3/76	050	5,420	5.16	0.316	5.73	8.2	G+rods, G-rods Ⓢ	
Dw-prim	2	11/3/76	051	3,820	1.51	< 0.020	2.87	8.1	G+rods, G-rods Ⓢ	
Dw-south	2	11/3/76	052	8,610	4.68	0.134	1.91	8.5		
Scale rm	2	11/3/76	047	47,800	0.163	0.020	3.82	8.0	G+rods, G-rods Ⓢ	Heavy mold count
Crane	2	11/3/76	048	66,950	2.11	0.316	100	8.9		Heavy mold count
Tip floor	2	11/3/76	046	41,100	0.468	0.468	411	10.0		
Downtown	2	11/3/76	053	< 497	0.655	< 0.020	< 0.992	7.5	G+rods, G-rods Ⓢ	
Packer trk-left	2	11/3/76	032	114,000	251	14.7	470	9.3		
Packer trk-right	2	11/3/76	033	Spreaders	3.76	1.24	235	9.3	G+rods Ⓢ	
Upwind	3	11/4/76	056	1,950	0.225	< 0.020	< 0.975	8.0		
Dw-north	3	11/4/76	057	2,740	1.19	0.120	3.67	8.4	G+rods, G-rods Ⓢ	
Dw-prim	3	11/4/76	058	2,498	1.67	0.099	1.87		Very high mold count	
Dw-south	3	11/4/76	064	12,480	0.016	< 0.020	1.91	8.4	Very high mold count	
Scale rm	3	11/4/76	063	Mold	< 0.017	< 0.017	1.48	10.2	Very high mold count	
Crane	3	11/4/76	061	111,500	0.295	< 0.018	72.3	10.9	Very high mold count	Heavy mold count
Tip floor	3	11/4/76	062	15,300	0.206	< 0.018	66.7	11.0	Very high mold count	
Downtown	3	11/4/76	065	1,820	0.199	0.039	0.907			
Packer trk-left	3	11/4/76	041	81,000	> 324	4.72	486	9.3	Very high mold count	Heavy mold count
Packer trk-right	3	11/4/76	045	13,500	> 324	3.24	446	9.1	G+rods, G-rods, high mold count	Heavy mold count
Blank	1	11/2/76	043	-	-	-	-	7.1		
Blank	3	11/4/76	077	-	-	-	-	6.8		

a/ Andersen samples correspond to the same location and date as Hi-Vol samples.

b/ Ⓢ indicates predominance of sporeformers (soil type).

TABLE H-2. PROCESSING PLANT (Hi-Vol)

	Test day	Date	Sample No.	Bacteria count/m³ (MPN): Total plate count	Total coliform	Fecal coliform	Fecal Streptococci	Filter slurry pH	Morphological characteristics of isolates: High-volume sampler	Andersen impactor sampler[a]
Upwind	0	11/8/76	059	2,900	1.06	< 0.020	2.90	8.5		
Dw-west	0	11/8/76	060	8,400	6.59	0.462	24.5	8.5		
Dw-prim	0	11/8/76	066	3,790	3.32	0.066	22.8	8.4	G+rods, G-rods Ⓢ[b]	
Dw-east	0	11/8/76	067	1,780	0.463	< 0.020	7.55	8.5		
Control rm	0	11/8/76	076	1.61×10^6	48.8	3.16	135	8.6	G+rods, G-rods Ⓢ high mold count	G+rods, G-rods, actinomycetes, 23% pigmented, high mold
Packer sta	0	11/8/76	075	2.67×10^5	> 213	21.3	478	8.8	G+rods, G-rods, high mold count	actinomycetes, high mold
Tip floor	0	11/8/76	074	2.60×10^5	> 208	30.4	417	8.8	Heavy mold count	G+rods, G-rods, actinomycetes, 16% pigmented
Downtown	0	11/8/76	068	1,200	0.590	< 0.025	1.20	8.5	G+rods, G-rods Ⓢ	
Upwind	1	11/9/76	072	11,900	2.33	0.767	38.9	8.7		
Dw-north	1	11/9/76	071	9,060	33.9	6.45	57.1	8.7		
Dw-prim	1	11/9/76	070	60,700	> 233	33.9	378	8.5		
Dw-south	1	11/9/76	069	78,000	3.45	0.079	31.5	8.5	G+rods, G-rods, actinomycetes	
Control rm	1	11/9/76	080	29,100	3.16	3.34	40.2	8.6	G+rods, G-rods Ⓢ	
Packer sta	1	11/9/76	079	24,800	12.4	1.63	31.6	8.7	G+rods, G-rods Ⓢ	
Tip floor	1	11/9/76	078	90,600	86.8	10.4	270	8.9	G+rods, G-rods Ⓢ	
Downtown	1	11/9/76	073	717	0.180	0.019	0.095			
Upwind	2	11/10/76	082	14,600	0.761	0.068	12.5	8.3	G+rods, G-rods Ⓢ	G+rods, G-rods, 30% pigmented
Dw-north	2	11/10/76	083	8,130	17.2	8.98	20.0	8.8		
Dw-prim	2	11/10/76	084	30,600	134	153	590	8.1	G+rods, G-rods Ⓢ	G+rods, G-rods, actinomycetes 14% pigmented
Dw-south	2	11/10/76	085	28,700	15.3	3.36	19.1	8.8	G+rods, G-rods, G-cocci	
Control rm	2	11/10/76	088	78,000	3.36	2.30	18.2	8.9	G+rods, G-rods Ⓢ	
Packer sta	2	11/10/76	087	3,820	0.755	0.755	10.5	8.9		
Tip floor	2	11/10/76	086	93,000	88.0	5.16	229	8.9	G+rods, G-rods Ⓢ	G+rods, G-rods, actinomycetes 57% pigmented
Downtown	2	11/10/76	089	956	0.029	< 0.029	0.956	8.5		
Upwind	3	11/11/76	091	2,810	0.312	< 0.020	5.68	8.5		
Dw-north	3	11/11/76	094	14,700	51.2	12.3	44.6	8.6		
Dw-prim	3	11/11/76	093	7,600	2.28	0.209	32.2	8.4		
Dw-south	3	11/11/76	092	959	0.106	< 0.020	0.969	8.3		
Control rm	3	11/11/76	097	20,500	10.5	6.39	43.9	9.0		
Packer sta	3	11/11/76	096	10,800	3.36	2.30	39.1	8.8	G+rods, G-rods Ⓢ mold	G+rods, G-rods, G-cocci Heavy mold count
Tip floor	3	11/11/76	095	50,300	15.2	1.52	287	9.1	G+rods, G-rods Ⓢ mold	G+rods, G-rods, 10% pigmented Heavy mold count
Downtown	3	11/11/76	099	6,780	0.48	< 0.020	< 0.956	8.4		
Blank	1	11/9/76	081	-	-	-	-	8.5		
Blank	2	11/10/76	100A	-	-	-	-	8.2		
Blank	3	11/11/76	098	-	-	-	-	8.2		

a/ Andersen samples correspond to the same location and date as Hi-Vol samples.

b/ Ⓢ indicates predominance of sporeformers (soil type).

TABLE H-3. WASTE TRANSFER STATION (HI-Vol)

	Test day	Date	Sample No.	Bacteria count/m^3 (MPN) Total plate count	Total coliform	Fecal coliform	Fecal streptococci	Filte. slurry pH	Morphological characteristics of isolates High-volume sampler	Andersen impactor sampler[a]
Upwind	1	11/22/76	131	< 477	0.020	< 0.020	< 0.953	8.2		
Dw-north	1	11/22/76	130	< 469	0.131	< 0.018	< 0.953	8.2		
Dw-prim	1	11/22/76	129	1,430	0.220	< 0.020	< 0.956	8.4		
Dw-south	1	11/22/76	123	478	1.61	< 0.020	< 0.956	8.5		
Trk ramp	1	11/22/76	146	22,900	2.29	0.458	107	9.8		
Tip floor-east	1	11/22/76	135	30,550	153	8.98	203	9.3	G+rods, G-rods Ⓢ[b]	
Tip floor-north	1	11/22/76	136	26,800	3.34	2.30	126	9.3	G+rods, G-rods Ⓢ	G+rods, G-rods, actinomycetes (15% pigmented)
Upwind	2	11/23/76	010	< 491	< 0.020	< 0.020	< 0.983	8.5	G+rods, G-rods Ⓢ	
Dw-west	2	11/23/76	009	1,820	22.9	3.36	3.82	8.1		
Dw-prim	2	11/23/76	001	478	0.325	< 0.020	< 0.956	8.6		G+rods, G-rods, G-cocci actinomycetes (20% pigmented)
Dw-east	2	11/23/76	149	< 477	0.163	< 0.163	< 0.953	8.0	G+rods, G-rods (75%) G-cocci (12%), actinomycetes (13%)	
Trk ramp	2	11/23/76	133	30,550	3.34	2.30	59.8	9.9		
Tip floor-east	2	11/23/76	134	7,830	2.26	1.22	26.3	9.2	G+rods, G-rods	G+rods, G-rods, G-cocci, actinomycetes (20% pigmented)
Tip floor-north	2	11/23/76	132	14,040	15.9	10.3	31.9	9.4	G+rods, G-rods (44%) G+cocci, G-cocci (34%) actinomycetes (22%)	
Upwind	3	11/24/76	110	2,910	0.224	0.068	4.86	8.1	G+rods, G-rods Ⓢ	
Dw-west	3	11/24/76	203	< 952	< 0.020	< 0.020	< 0.952	8.7		G+rods, G-rods, G-cocci, actinomycetes
Dw-prim	3	11/24/76	202	< 469	2.26	0.311	5.64	8.1		
Dw-east	3	11/24/76	201	714	0.315	< 0.029	1.43	8.3	G+rods, G-rods Ⓢ	
Trk ramp	3	11/24/76	150	6,340	2.07	0.143	6,340	9.1		Excessive mold growth
Tip floor-east	3	11/24/76	014	2,870	3.34	0.439	14.3	8.8		
Tip floor-north	3	11/24/76	015	20,000	22.9	0.702	44.5	9.0	G+rods, G-rods, G-cocci, actinomycetes (51%)	
Blank	1	11/22/76	109	-	-	-	-	9.0		
Blank	2	11/23/76	147	-	-	-	-	8.3		
Blank	3	11/24/76	204A	-	-	-	-	8.4		

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a/ Andersen samples correspond to the same location and data as Hi-Vol samples.

b/ Ⓢ indicates predominance of sporeformers (soil type).

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TABLE II-4. WASTEWATER TREATMENT PLANT (Hi-Vol)

	Test day	Date	Sample No.	Bacteria count/m^3 (MPN) Total plate count	Total coliform	Fecal coliform	Fecal streptococci	Filter slurry pH	Morphological characteristics of isolates High-volume sampler	Andersen impactor sampler[a/]
Upwind	1	11/15/76	100	2,700	0.447	0.027	< 1.35	8.4		
Dw-north	1	11/15/76	101	< 1,590	0.350	< 0.031	1.59	8.5		
Dw-prim	1	11/15/76	102	3,980	1.05	< 0.026	< 1.33	8.5	G+rods, G-rods Ⓢ[b/] G-cocci	
Dw-south	1	11/15/76	103	1,560	0.170	< 0.031	< 1.56	8.6		
Prim set	1	11/15/76	106	< 833	0.134	< 0.034	< 1.66	8.5		
Aeration	1	11/15/76	107	< 1,790	0.036	< 0.036	< 1.79	8.7		
Pressrm	1	11/15/76	104	< 1,530	0.061	< 0.061	< 1.53	9.0		
Pressrm bsmt	1	11/15/76	105	< 1,500	0.120	< 0.030	< 1.50	8.3		
Upwind	2	11/16/76	115	517	0.021	< 0.021	< 1.04	7.9		
Dw-west	2	11/16/76	118	478	0.048	< 0.020	< 0.956	8.0		
Dw-prim	2	11/16/76	117	< 477	< 0.020	< 0.020	< 0.953	8.2		
Dw-east	2	11/16/76	116	< 952	< 0.020	< 0.020	< 0.952	8.0		
Prim set	2	11/16/76	113	< 477	< 0.020	< 0.020	< 0.956	8.2		
Aeration	2	11/16/76	114	< 477	< 0.020	< 0.020	< 0.953	8.0		
Pressrm	2	11/16/76	111	< 478	< 0.020	< 0.020	< 0.956	9.2	G+rods, G-rods Ⓢ	G+rods, G-rods, G-cocci, actinomycetes (40% pigmented)
Pressrm bsmt	2	11/16/76	112	< 473	< 0.020	< 0.020	< 0.946	7.9		
Upwind	3	11/17/76	125	< 477	< 0.020	< 0.020	< 0.953	8.6		
Dw-west	3	11/17/76	126	5,720	0.048	< 0.020	< 0.953	8.5		
Dw-prim	3	11/17/76	127	477	< 0.020	< 0.020	< 0.953	8.4		
Dw-east	3	11/17/76	128	478	< 0.020	< 0.020	< 0.956	8.5		
Prim set	3	11/17/76	119	< 478	0.029	< 0.020	< 0.956	8.5		Moderate mold growth
Aeration	3	11/17/76	120	< 478	0.038	< 0.020	< 0.956	8.6	G+rods, G-rods	
Pressrm	3	11/17/76	121	2,380	0.077	< 0.020	< 0.953	9.3	G+rods, G-rods	
Pressrm bsmt	3	11/17/76	122	478	0.077	< 0.020	< 0.956	8.2	G+rods, G-rods	G+rods, G-rods (26%), G-cocci (4%), actinomycetes (50% pigmented)
Upwind	4	11/18/76	144	< 492	< 0.020	< 0.020	< 0.985	8.6		
Dw-west	4	11/18/76	143	< 478	< 0.020	< 0.020	< 0.956	8.7		
Dw-prim	4	11/18/76	142	492	0.039	0.020	< 0.985	8.2	G+rods, G-rods	G+rods, G-rods, actinomycetes, (40% pigmented)
Dw-east	4	11/18/76	145	< 478	0.020	< 0.020	< 0.956	8.1		
Prim set	4	11/18/76	138	1.74 × 10^5	0.020	< 0.020	< 0.956	8.5	G+rods, G-rods	
Aeration	4	11/18/76	139	11,750	< 0.020	< 0.020	< 0.956	8.5		
Pressrm	4	11/18/76	140	3,820	0.755	< 0.020	< 0.956	8.5	G+rods, G-rods	
Pressrm bsmt	4	11/18/76	141	< 956	0.020	< 0.020	< 0.956	8.3	G+rods, G-rods, actinomycetes	G+rods, G-rods, G-cocci, actinomycetes (50% pigmented)
Blank	2	11/16/76	108	-	-	-	-	9.3		
Blank	3	11/17/76	137	-	-	-	-	9.0		
Blank	4	11/18/76	148	-	-	-	-	9.0		

a/ Andersen samples correspond to the same location and date as Hi-Vol samples.

b/ Ⓢ indicates predominance of sporeformers (soil type).

TABLE B-5. SANITARY LANDFILL (Hi-Vol)

				Bacteria count/m^3 (MPN)					Morphological characteristics of isolates	
	Test day	Date	Sample No.	Total plate count	Total coliform	Fecal coliform	Fecal streptococci	Filter slurry pH	High-volume sampler	Andersen impactor sampler[a/]
Upwind	1	11/29/76	209	< 478	0.211	< 0.020	< 0.956	8.4		
Dw-east	1	11/29/76	208	< 478	< 0.020	< 0.020	< 0.956	8.3		
Dw-prim	1	11/29/76	207	1,410	0.316	0.020	< 0.956	8.3		-
Dw-west	1	11/29/76	206	< 478	3.16	0.325	< 0.956	8.5		
Work face-east	1	11/29/76	205	2,190	0.536	0.360	< 1.09	8.4	G+rods, G-rods	-
Work face-west	1	11/29/76	214	< 536	< 0.021	< 0.021	< 1.07	8.1		-
Scale-off	1	11/29/76	215	< 478	0.048	< 0.020	< 0.956	8.4		
Upwind	2	11/30/76	216	239	< 0.020	< 0.020	< 0.956	8.1		
Dw-east	2	11/30/76	219	239	< 0.020	< 0.020	< 0.956	8.6		
Dw-prim	2	11/30/76	218	200	0.048	< 0.020	< 0.956	8.0	Actinomycetes	
Dw-west	2	11/30/76	217	1,190	0.048	< 0.020	< 0.956	8.6		-
Work face-east	2	11/30/76	213	< 95.6	< 0.020	< 0.020	< 0.956	8.4		-
Work face-west	2	11/30/76	212	143	< 0.020	< 0.020	< 0.956	8.5	G+rods, G-rods	-
Scale-off	2	11/30/76	211	< 95.6	< 0.020	< 0.020	< 0.956	8.3		
Upwind	3	12/01/76	225	944	< 0.020	< 0.020	< 0.944	8.4		
Dw-east	3	12/01/76	224	203	< 0.021	< 0.021	< 1.01	8.6		-
Dw-prim	3	12/01/76	223	99.7	< 0.020	< 0.020	< 0.997	8.6		-
Dw-west	3	12/01/76	226	< 95.2	< 0.020	< 0.020	< 0.952	8.7	G-rods	-
Work face-east	3	12/01/76	222	1,680	3.16	0.161	< 0.956	8.6		
Work face-west	3	12/01/76	221	2,590	16.3	16.3	6.70	8.6		G+rods, G-rods, G-cocci
Scale-off	3	12/01/76	220	< 95.6	< 0.020	< 0.020	< 0.956	8.4		
Blank	1	11/29/76	210	-	-	-	-	8.9		
Blank	2	11/30/76	220C	-	-	-	-	8.7		
Blank	3	12/01/76	227	-	-	-	-	9.2		

[a/] Andersen samples correspond to the same location and date as Hi-Vol samples.

APPENDIX I

A LITERATURE REVIEW OF THE HEALTH ASPECTS OF AIRBORNE MICROORGANISMS IN WASTE TREATMENT INDUSTRIES

OBJECTIVES OF LITERATURE REVIEW

This literature review had a fourfold objective:

1. To survey various waste treatment industries in order to place health problems from bacterial and viral emissions from MSW processing plants in proper perspective.

2. To identify any deficiencies in the current state of knowledge concerning bacterial and viral dose/response relationships.

3. To evaluate airborne microorganism sampling and analysis procedures.

4. To evaluate possible control techniques for microorganisms in MSW processing plants.

INDUSTRIES SURVEYED

The specific industries considered in this literature review were:

1. Refuse collection and handling;

2. Sewage treatment; and

3. Wastewater treatment.

BACKGROUND INFORMATION

Characteristics of Microorganisms of Interest

Bacteria--

Bacteria are among the smallest microorganisms. In unstained preparations, bacteria can be seen only with difficulty in the conventional light microscopes (17) (see Table I-1). The diameter of the cell may vary from 0.5 to 1.0 μm, and only a few genera have cell diameters larger than 1.0 μm. The lengths of bacterial cells vary greatly. Spherical-shaped cells, called cocci, are about the same length as width. Rod-shaped bacteria can vary from lengths of 1 to 2 μm to as much as 10 μm. Cells many times longer than wide are not called rods, but filaments. Certain groups of bacteria are characteristically filamentous, but in other groups in which the organisms are normally rod-shaped, filaments are formed under abnormal conditions.

TABLE I-1. COMPARATIVE SIZE OF MICROORGANISMS AND CELLS (17)

Microorganism	Size (nm)[a]
Animal cell	10,000
Animal cell nucleus	2,800
Bacterial cell	1,000 by 2,000-3,000
Smallpox virus	200
Influenza virus	100
Adenovirus	70
Polio virus	28

[a] nm = nanometer = 10^{-9} m.

Primarily because of the rather limited range of morphological forms possible and also because of the small size and the difficulty of observing details of structure under the microscope, bacteria can rarely be identified as to their species or even genus on the basis of microscopic observation alone. The usual procedure is to make observations of size, shape, and cell arrangement, look for motility and spores, and perform a Gram stain. From these characteristics a preliminary idea of the kind of organism being dealt with can be determined, but further work on the nutrition, metabolic products, and environmental requirements and tolerances of the organism must be carried out (described below) to permit positive identification. (17)

Fungi--

Although the fungi are a large and rather diverse group, only two kinds of fungi are of importance here. These are the molds and yeasts. Fungi can be distinguished from algae because the fungi do not have chlorophyll and thus are not green. Fungi can be differentiated from bacteria by the fact that fungal cells are much larger, and vacuoles, nuclei, and other intracellular organelles can usually be observed. (17)

The molds are filamentous fungi. An individual mold filament may have crosswalls or they may be absent. The filament grows mainly at the tip, by extension of the existing cell. The hyphae usually grow together across a surface to form rather compact tufts, collectively called a mycelium. (17)

The yeasts are unicellular fungi. The cells are usually spherical, oval, or cylindrical. Neither filaments nor a mycelium results, and the population of yeast cells remains a loose amorphous mass. Yeast cells are considerably larger than bacterial cells and can be distinguished from bacteria by their size and by the obvious presence of internal cell structures. For the most part, yeasts spread from place to place as ordinary vegetative cells rather than as spores. (17)

Classification of yeasts is based partly on the kinds of sexual spores formed and partly on the basis of nutrition and biochemistry. The classification of yeasts is even more specialized than the classification of molds. (17)

Protozoa--

Protozoa are unicellular, colorless, generally motile organisms that lack a cell wall. They are distinguished from bacteria by their size, from algae by their lack of chlorophyll, and from yeasts and other fungi by their motility and absence of cell wall. Protozoa usually obtain food by eating other organisms or organic particles. They eat by surrounding the food particle with a portion of their flexible membrane and engulfing the particle or by swallowing the particle through a special structure called the gullet. An organism that destroys bacteria is termed a bacteriophage and was potentially important in this study. (17)

Viruses--

Viruses are not cells. They are particles that are inert by themselves, and they do not carry out any of the functions of cells. Only when a virus particle becomes associated with a host cell does it begin to function. Within the host, a virus is able to reproduce itself, using the machinery of the host for most essential functions. The virus thus alternates between two states, the extracellular and the intracellular. (17)

In the extracellular state, the virus particle, also called the virion, is composed of a molecule of nucleic acid, either ribonucleic acid (RNA) or deoxyribonucleic acid (DNA), surrounded by a coat composed of protein. When the virus particle infects a host cell, the nucleic acid separates from the protein coat and the reproduction process within the cell begins. At the end of the reproduction cycle, molecules of nucleic acid and protein molecules join and reform new virus particles that become liberated from the dying cell. These virus particles can then infect other cells, and the process continues. When viruses do reproduce in cells, they usually damage or kill the cells, and in this way viruses are agents of disease. However, viruses do not always reproduce when they infect cells. Sometimes the virus nucleic acid becomes associated with the host nucleic acid and a stable relationship occurs. Such viruses are called latent. (17)

Qualitative and Quantitative Procedures for Aerosolized Microorganisms

Microorganism Identification--

The easiest and most commonly used procedure for isolating pure cultures is agar streaking. This procedure involves preparation of petri plates containing a suitable culture medium solidified with agar. A sterile inoculating loop is placed in a mixed culture containing the organism of interest and then lightly streaked across the surface of the agar plate. As the plate is streaked, organisms are gradually dislodged from the loop, and in the final parts of the streak single organisms which are well separated from each other will be deposited. The streaked plate is then incubated so that the organisms will multiply and produce colonies. In the initial parts of the streak these colonies will be very close together, but in the final part well-isolated colonies should be obtained. It is assumed that a colony well isolated from all other colonies will have arisen from a single cell. One of the well-isolated colonies is then streaked on a fresh agar plate, which is incubated. If all of the colonies obtained are of similar size, shape, color, and texture, it is presumed that they are all alike and that a pure culture has been obtained. (17)

A variant of the above procedure is to prepare pour plates, in which a diluted inoculum is mixed with the melted agar before pouring into plates. When the inoculated poured plates are incubated, isolated colonies should be obtained from which pure cultures can be prepared. (17)

Another variation is the use of membrane filters as the solid support instead of agar. A dilution of the inoculum can be passed through the filter, and the filter is then placed on an appropriate culture medium for incubation. Isolated colonies developing on the filter can then be picked to prepare pure cultures. (17)

It is important to verify that cultures isolated as pure are indeed so. A check of purity begins with careful microscopic examination to ensure that only one cell type is present. A second check is to be sure that all colonies obtained upon agar streaking are alike. As a final check, one can select several colonies from an agar streak and determine their nutritional and environmental requirements, which should be identical in pure cultures. (17)

Microorganism Population Measurements--

The number of cells in a population can be measured by direct microscopic count. Two kinds of direct microscopic counts are done, either on samples dried on slides or on samples in liquid. With liquid samples, special counting chambers are used. (17)

There are two types of chambers for counting cell number in liquid samples: the hemocytometer, or blood cell-counting chamber, for use with organisms 3 to 4 µm in diameter or larger; and the Petroff-Hausser counting chamber, for use primarily with bacteria. In both of these chambers, a calibrated grid is marked on the surface of the glass slide. A flat cover slip is placed on top of the grid, and a ridge on each side of the grid holds the cover slip off the grid by a defined distance. Thus over each square on the grid is a volume of known size. A sample of the suspension to be counted is allowed to fill the counting chamber. After the cells have settled in the chamber, the number per unit area of grid is counted giving a measure of the number of cells per chamber volume. Converting this value to number of cells per milliliter of suspension is done by multiplying by a conversion factor based on the volume of the chamber sample. (17)

Direct microscopic counting is tedious but is a good way of estimating microbial cell number. However, it has certain limitations: (a) dead cells cannot usually be distinguished from living cells; (b) small cells are difficult to see under the microscope and some cells may be missed; (c) precision is difficult to achieve; and (d) the method is not suitable for cell suspensions of low density. With bacteria, if a cell suspension has less than 10^6 cells/ml, no bacteria will be seen. (17)

In the methods just described both living and dead cells are counted. In many cases one is interested in counting only live cells since these affect us most, and for this purpose viable cell counting methods have been developed The usual way to perform a viable count is to determine the number of cells in the sample capable of forming colonies on a suitable agar medium. For this reason, the viable count is often called the plate count or colony count. (17)

There are two ways of performing a plate count--the spread plate method and the pour plate method. With the spread plate method, a volume no larger than 0.1 ml is spread over the agar surface. The plate is then incubated until the colonies appear, and the number of colonies is counted.

In the pour plate method, a known volume of 0.1 to 1.0 ml is mixed with a melted agar medium and poured into a sterile petri plate. Because the sample is added to the liquid agar medium, a larger volume can be used than with the spread plate; however, with the pour plate the organism must be able to withstand the temperature of melted agar, 45°C.

With both the spread plate and pour plate methods, it is important that the number of colonies developing on the plates not be too large, since on crowded plates some cells may not form colonies and the count will be erroneous. It is also essential that the number of colonies not be too small, for then the accuracy of counting will be low. The usual practice, which is most valid statistically, is to count only those plates that have between 30 and 300 colonies. To obtain the appropriate colony number, the sample to be counted must usually be diluted.

A similar technique is used for quantifying viruses; however, since viruses require a viable host cell to replicate, the culture medium is usually a cell monolayer. Results are reported as plaque forming units (pfu).

Some organisms do not readily form colonies on agar plates or membrane filters but will initiate growth in liquid medium. To count such organisms, the most probable number (MPN) method has been developed, which permits an estimate of viable numbers after incubation in liquid medium. With this method, the sample is diluted to the point where some but not all aliquots contain a cell. If a series of tubes is inoculated with identical aliquots taken at this dilution, after incubation some will show growth whereas others will not. By counting the fraction of tubes showing growth, one can estimate the viable count, using statistical tables.

Aerosolized Microorganism Sampling--

A primary obstacle to accurately quantifying the bacterial and viral population at an MSW processing plant is obtaining a representative sample.

Table I-2 shows several different types of samplers widely used to collect microorganisms. A review of field research work indicates that the Andersen sampler is generally preferred but the all glass impinger (AGI) is also frequently used. According to Hickey and Reist (66) the Andersen sampler possesses the following features that are required to adequately evaluate the health implications of viable microbial aerosols:

1. High collection efficiency in the 1 to 10 μm particle size range;

2. Ability to quantify viable particles per unit volume of air; and

3. Minimize the logistic problems of sampling.

Even though the Andersen sampler has the capability of classifying particles according to size, none of the researchers used this capability to obtain particle size spectra of sampled aerosols. This is rather surprising in light of the well-established fact that particle size has an influence on the degree of retention and on the site of deposition of inhaled particles.

TABLE I-2. SOME WIDELY USED SAMPLERS FOR AIRBORNE MICROORGANISMS[a] (44)

Type of sampler	Collection medium	Remarks
Sedimentation		
Open petri dish	Agar surface	Collects viable particles for direct microscopic observation or colony growth. Generally limited value for quantitative measurement of airborne particles.
Filtration		
Membrane filter[b]	Membrane	Usefulness depends upon bacterial resistance to desiccation during collection. Quantitation good for spores and resistance microbial forms. High collection efficiency.
Impingement		
All glass impinger[c] (12)	Liquid	Low sampling rate (6 or 12.5 liters/min). Not well adapted to low concentrations of microbial particles. Disruption of bacterial particles. High efficiency of collection. Some viability loss with high velocities of impingement and extended continuous sampling. High-vacuum source required.
Impaction		
TDL[d] (slit type)	Agar surface	Sampling rate of 28.3 liters/min. Renders time-concentration relationship. Collects unmodified particles. No dilution or plating procedures required. Not well adapted to high concentrations. Results expressed as particles per unit volume of air.
Reyniers[e]	Agar surface	Sampling rate of 28.3 liters/min. Renders time-concentration relationship. Collects unmodified particles. No dilution or plating procedures required. Not well adapted to high concentrations. Results expressed as particles per unit volume of air.
Andersen[f] (sieve type)	Agar surface	Collects and separates unmodified particles into six size ranges. Size distribution of particles can be determined. No plating procedures required. Only fairly well adapted to high concentrations. Large numbers of plates required. Sampling rate 28.3 liters/min. Results expressed as particles per unit volume of air.

[a] Use of trade names and commercial sources is for identification only and does not constitute endorsement.

[b] Gelman Instrument Company, 600 South Wagner Road, Ann Arbor, Michigan 48106; Millipore Filter Corporation, Bedford, Massachusetts 01730.

[c] Ace Glass, Inc., Vineland, New Jersey 08360.

[d] Engineering Development and Products, Inc., 250 Freeman Street, Decatur, Georgia 30030.

[e] No longer commercially available; included because this sampler is still widely used.

[f] 2000 Inc., 5899 South State Street, Salt Lake City, Utah 84107.

Sitting (133) reports that general agreement was reached at the International Aerobiology Symposium, sponsored by the Office of Naval Research and the University of California, on the use of the all glass impinger (AGI-30), as the standard liquid sampler and on the Andersen stacked sieve sampler as the standard apparatus for collection of aerosols.

The effect of agar nutrient drying for long sampling times is a common cause of microorganism die-off. According to May, a medium which is otherwise satisfactory, when used as a substrate in an air sampler, may dry out, resulting in increased concentration of growth inhibitors. (55)

If agar plates used in the Andersen sampler are coated with oxyethylene docosand (OED), moisture evaporation is retarded without affecting colony growth (65,66). OED is applied to the nutrient agar by pouring an excess of a sterilized 0.2% emulsion over thoroughly dried agar and immediately draining the excess into the next plate to be treated, and so forth. With OED, the Andersen sampler can be operated for an entire day, sampling 13,000 liters of air, with less than 2 g of water loss per plate. (65)

Some potentially useful new developments in air sampling devices for microorganisms are given in Table I-3.

TABLE I-3. NEW DEVELOPMENTS IN AIRBORNE SAMPLING OF MICROORGANISMS

Sampler	Remarks
Pagoda sampler (65)	Three stages standard, but number of stages can be increased. Sampling time: 3 min, flow rate 1,000 liters/min, British patent.
Modified cascade sieve sampler (MCS) Modified Andersen sampler (65)	Eight stages with 6 hr continuous run possible, flow rate 28 liters/min.
Man-operated particulate aerosol sampler (112)	Mainly for ambient indoor use to obtain actual exposure. Operated by human breathing.
The DRES-modified large volume air sampler (cyclone scrubber) (150)	High collection efficiency for airborne bacterial spores and vegetative cells. Flow rate 950 liters/min. Developed by Defense Research Establishment, Alberta, Canada.

DOSE/RESPONSE RELATIONSHIPS

General Discussion

Microorganisms are ubiquitous and they play an important role in human life--some are beneficial while others adversely affect health. Potential health hazards may exist due to the presence of microorganisms (viruses and bacteria) in solid wastes, raw sewage, and wastewater effluent because workers in these industries come in direct and indirect contact with these potentially dangerous pathogens. Contamination may cause infection and a disease may result, depending on the degree of contamination as well as other factors. Indirect infection processes may begin from airborne microorganisms, waterborne microorganisms, or by transmission from person to person (clinically direct route). Microbiological population in different environments is shown in Table I-4.

TABLE I-4. MICROBIOLOGICAL POPULATION IN DIFFERENT ENVIRONMENTS (3,65)

Sampling place	Bacteria/m^3 air	Coliforms/m^3 air
Sewage treatment plant	700,000	850
Garbage destruction plant	13,000	480
Chicken slaughterhouse	30,000	
Printing office[a]	50,000	
Sawmill	14,000	
Laboratory	200	
Animals' room	900	
Country air[b]	1,977	
General offices and school[b]	3,354	
City streets[b]	2,542	
Factories[b]	3,989	

[a] The high numbers in the printing office were caused by a heavily contaminated air humidifier of fan type.

[b] Total microbial level (colonies).

The major routes that may be considered an infection threat are respiratory and oral (airborne), dermal and oral (direct physical contact), and oral (waterborne or foodborne). Multiple routes of entry that may cause infection present a complex problem. (17,26)

Airborne microorganisms on dust particles and in droplets or "droplet nuclei" (residue remaining after evaporation) complicate the probability of infection due to their selective landing sites--either nasal, upper respiratory or lower respiratory tracts, and intestines through any of the possible routes. (26,112,65)

Table I-5 indicates microorganisms that may cause potential health hazards. There also may be infections by protozoa, through oral routes, primarily from food and water.

Man, like other animals, is always infected by many species of microorganisms, almost any of which, under the right circumstances, is capable of producing disease. The probability of bacterial infection primarily depends on four factors:

1. Source;

2. Concentration;

3. Capability to survive; i.e., transmittability from source to host in concentrations that can induce infection; and

4. Susceptibility of the host. (20)

There is a paramount distinction between infection and disease from a clinical point of view. The mere fact that a bacteriologist can culture a given microbe from a patient's body may be totally irrelevant. For example, over 90% of random throat cultures may be positive for a given kind of Streptococcus. (26) Health people can be infected and still not contract disease because body tissues possess efficient natural mechanisms of antibacterial defense.

Those microorganisms which are pathogenic under the right circumstances can often coexist with the host in a truce that is only occasionally broken. Pathogenicity or virulence, then, may vary over a wide range depending upon the "strain of microbe," "the strain of host" (i.e., host's resistance, etc.), and the conditions under which they are brought together. (26) For example, the causative organism of diphtheria is normally found only in the upper respiratory tract of men, cattle, and horses. Infection in man may remain subclinical or the bacilli may proliferate extensively. (20)

Biological aerosols are self-replicating and there probably is no true tolerance threshold; in theory, at least, one viable particle may infect an individual and subsequently cause an epidemic in a fully susceptible population. However, for many diseases more than a single organism may be required to initiate clinical infection. (70)

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TABLE I-5. INFECTIONS AND DISEASES CAUSED BY MICROORGANISMS (17.26)

Infection	Microorganisms	Route	Source
Bacterial			
Typhoid fever	Salmonella typhosa[a]	Oral/nasal	Water, food, fecal materials, also raw sewage
Paratyphoid	Salmonellae paratyphosi[a]	Oral/nasal	
Bascilli dysentery (Shigeliosis)	Shigella	Oral/nasal	
Pyogenic infections and food poisoning	Staphylococcus aureus and others	Nasal	Humans, transmittal through dishes, bedding, etc.
Skin rash	Fecal streptococci	Oral	Water, fecal material, contaminated food, raw sewage
Kidney infections	Group A		
Mild respiratory infections in man	Group C		
Mild genital tract infections in dogs	Groups L and M		
Viral			
Polio[b]	Pilio virus	Oral/nasal	Water, food, fecal material (disposal diapers), humans
Influenza[b]	Influenza virus	Nasal/oral	Humans
Measles	Virus	Respiratory-Nasal/oral	Humans
Common cold	Various viruses	Respiratory	Humans
Infectious hepatitis	Virus	Oral	Water, food (shellfish and clams)
Coxsacki viral	Viruses	Oral	Fecal material, pharyngeal secretion
Adenoviral	Viruses	Respiratory	Humans
Fungal			
Systemic mycoses			
Cryptococcosis	Cryptococcus neoformans	Lungs, meninges	-
Coccidioidomycosis	Coccidioides immitis	Lungs	-
Histoplasmosis	Histoplasma capsulatum	Lungs	-
Blastomycosis	Blastomyces dermatitidis	Lungs, skin	-
Candidiasis	Candida albicans	Oral cavity, intestinal tract	-
Aspergillosis	Aspergillus fumigatus	Bronchi	-
Superficial mycoses (dermatomycoses)			
Ringworm	Microsporum audouini	Scalp of children	-
Favus	Trichophyton schoenleinii	Scalp	-
Athlete's foot	Epidermophyton and other genera	Between toes, skin	-

[a] Gastrointestinal.

[b] Enteric viruses.

The number of organisms present in a given sample will be directly related to their initial concentration and subsequent survival rate. Finkelstein concluded that airborne transmission of human and animal diseases is essentially limited to indoor spaces and closely confined outdoor spaces. His rationale was that pathogens cannot reproduce in air and generally do not survive long because of adverse conditions of temperature, humidity, and sunlight. (70)

Any advanced microbiology text would show that survival or infectivity of viruses decreases as dilution increases. Dilution of viral aerosols by air (either in a confined space or in an open space) would thus probably reduce LD_{50} and ID_{50}.*

In virus assays an important factor is the ratio of the total number of viral particles to the number of infectious units. This ratio measures the efficiency of infection, which varies widely among different viruses (e.g., polio viruses 30 to 1,000 to 1, influenza viruses 7 to 10 to 1) and even for the same virus assayed in different hosts. (26) For most viruses the ratio is larger than unity. This result is due, in part, to the presence of noninfectious particles, and in part to the failure of potentially infectious particles to reproduce. However, even with the highest ratio of particles to infectivity, infection may be initiated by a single virus. (26)

It has been demonstrated that influenza antibodies can be diffused across mucous membrane to appear in respiratory secretions. Sufficient concentrations of antibodies can neutralize viruses prior to their penetration of cells and this in turn would prevent infection. (25) To infect, viruses must escape from the source in a for that allows transmission. It is possible to transmit influenza viruses through air in the laboratory.

Bang et al. (15) explained that there is a possibility of epidemiological interference or competition among enteric viruses which may delay the process of natural immunization. Such epidemiological interference would keep the rate of infection below the maximum which would otherwise occur.

There is a basic distinction between the roles of air and water as media for the transmission of microorganisms. Organisms introduced into water at one place and time are mechanically transported elsewhere to reach a new host at some distance and at some other time. Water as a vehicle is static; that is, it can be assumed that a sample examined at a reservoir is reasonably representative of the risk at some distant point of delivery. In contrast, air is dynamic. The processes of sedimentation and dilution are constantly in evidence so that a given sample is a measure of risk only at that time and at that place of sampling. (117)

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* LD_{50} is the lethal dose required for 50% of the receptors, while ID_{50} is the infective dose required for 50% of the receptors.

As pointed out previously, infection and disease are distinct and infections may even benefit the host if the presence of relatively avirulent bacteria at a given tissue site prevents the growth of more virulent species. (26) Considering the communicability of bacterial infections, Bernard et al. (26) indicated that to be naturally pathogenic for a given animal species, a bacterial strain must be readily transmissible to a susceptible individual.

Further, Bernard et al. (26) pointed out four factors on which the efficiency of transmission depends. They are:

1. There must be a ready source of the infecting agent.

2. The source must release relatively large numbers of organisms, the rate of release being dependent on the nature of the source.

3. To be transmitted, the infective microbe must be capable of surviving in transit to a new host--whether transported by droplet, dust, food, water, or insect vector; but neither mere survival in transit nor the cultivation of a microorganism from air and/or dust necessarily indicate that it is infectious.

4. For a bacterial disease to be widespread in a community, a relatively high proportion of the population must be susceptible.

Expanding on the third factor mentioned above, survival of microorganisms during transmission introduces the concept of viability. Viability is generally considered as the potential for multiplication under experimentally defined conditions, but all cells that are viable do not infect. (54) For viruses, definitions become more complicated because so called viability is measured conventionally in terms of infectivity for an egg, tissue culture, or animal host. Viability and infectivity of airborne organisms must be considered only in relation to the experimental conditions used to generate the data.

Survivability of Microorganisms

The survival of pathogens determines their viable concentration in transport media, and their eventual reception by a susceptible host (see Table I-6). The obstacles that microorganisms have to overcome before reaching a susceptible host are shown in Figure I-1. The numbers shown in Figure I-1 are arbitrary, serving only to provide a qualitative picture of a complex series of

TABLE I-6. SURVIVAL TIME OF VARIOUS ORGANISMS (126)

Organism	Medium	Type of application	Survival time
Ascaris ova	Soil	Sewage	Up to 7 years
	Vegetables	AC[a]	27-35 days
B. Typhosa	Soil	AC	29-70 days
	Vegetables	AC	31 days
Cholera vibrios	Spinach, lettuce	AC	22-29 days
	Nonacid vegetables	AC	2 days
Coliform	Grass	Sewage	14 days
	Tomatoes	Sewage	35 days
Endamoeba histolytica	Vegetables	AC	3 days
	Soil	AC	8 days
Hookworm larvae	Soil	Infected feces	6 weeks
Leptospira	Soil	AC	15-43 days
Polio virus	Polluted water	-	20 days
Salmonella typhi	Radishes	Infected feces	53 days
	Soil	Infected feces	74 days
Shigella	Tomatoes	AC	2-7 days
Tubercle bacilli	Soil	AC	6 months
Typhoid bacilli	Soil	AC	7-40 days

[a] AC = artificial contamination.

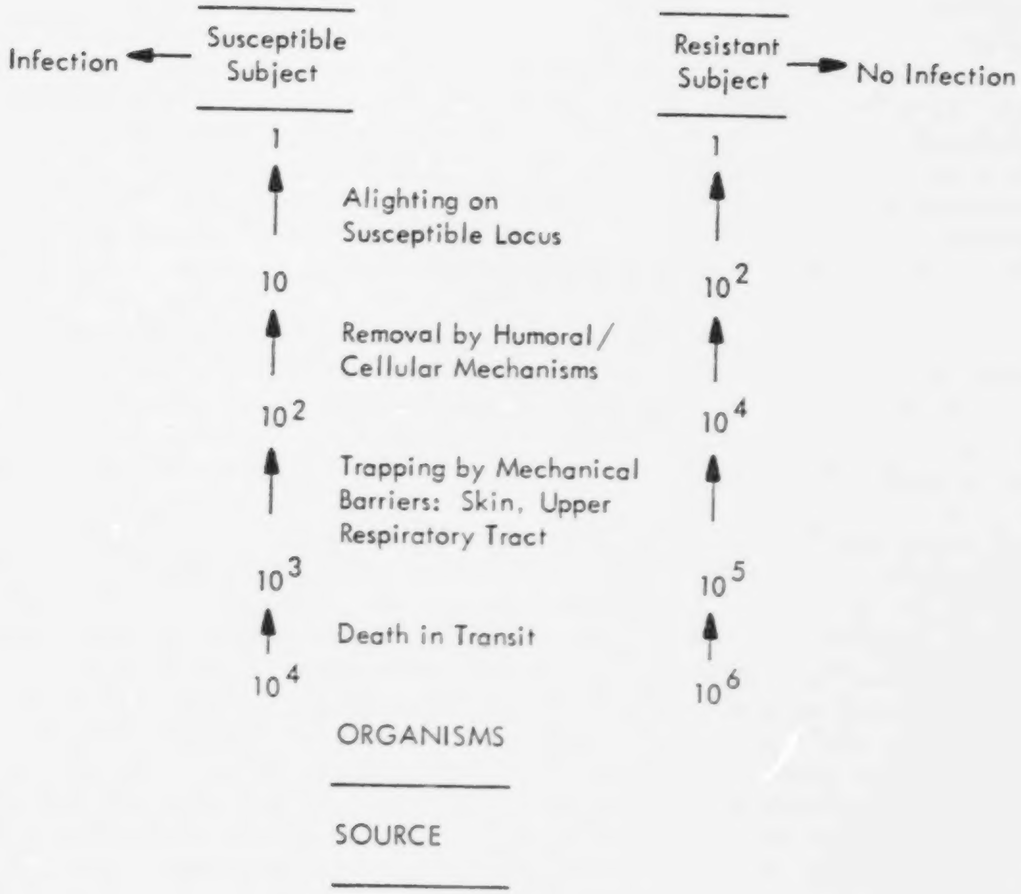
Infection
Susceptible Subject
Resistant Subject
No Infection
1
1
Alighting on Susceptible Locus
10
10^2
Removal by Humoral/ Cellular Mechanisms
10^2
10^4
Trapping by Mechanical Barriers: Skin, Upper Respiratory Tract
10^3
10^5
Death in Transit
10^4
10^6
ORGANISMS
SOURCE

Figure I-1. Qualitative representation of microorganism obstacles. (122)

events. Pathogens can survive only in special conditions that vary for each species, and there must be a suitable infection site in the host. (26,65,122)

Microorganisms such as coliform and fecal coliform may thrive in solid waste. However, these same microorganisms will survive for a lesser amount of time in hostile media like air or even water. Nevertheless, these microorganisms are used as indicators of pathogens, and under different environmental stresses such indicators may die while pathogens survive and vice versa. As it is not possible to duplicate all environmental stresses in the laboratory, experiments conducted in laboratories provide only partial information. Similarly, some difficulties are encountered in field experiments performed to collect data on the potential health hazards of microorganisms. Various researchers have expressed different opinions regarding the effects of environmental stresses, but all experiments prove that pathogens need special environmental conditions to survive in transit.

Even if a microorganism does survive, its effect depends on the resistance of the receptor and this can vary among the cells within a complex unit such as the human body. A single microbe can infect a susceptible cell. Practically, large numbers of microbes are required to start infection and the process depends on the way they are delivered to the susceptible host.

Many researchers have conducted laboratory experiments to investigate the effects of various environmental factors on microbe survival. Even though these data are for specific conditions (in the laboratories) they may be used for extrapolation to field situations. For example, if a pathogen does not survive under certain conditions in the laboratory, it may be concluded that it will not survive under similar conditions in the external environment, which is usually more harsh. Each species of pathogen has specific conditions under which it can infect a susceptible host. If these conditions do not exist, then the microorganisms may not survive, or if they survive, they may not replicate. Thus, their concentration may remain constant or decline depending on the protection they have either from the source or from the medium. (26,65,122)

One researcher found that Salmonellae inoculated into samples of poultry excretion declined to very low numbers or disappeared within a month. An overall reduction of 99% was observed in 19 days when inoculated at 9 to 12°C. They disappeared in 11 days at 18 to 20°C, and in 3 days at 30°C. In addition, room temperature drying had a profound effect, killing Salmonellae up to 99.5%. (10)

The effect of temperature on the reduction of Salmonellae is also prominent in other nonsterile media such as sewage, polluted river waters, and sewage treated soil. At higher temperatures of 18 to 37°C, 99.0% reduction is achieved in 3 days in poultry excreta, in 4 to 5 days in sewage treated subsurface soil, and in 4 days in sewage. (10)

The overall conclusion based on these studies is that sunlight, high temperature, and low humidity are all deleterious to bacterial survival.

In one study, alfalfa plants were irrigated with treated municipal sewage and it was found that fecal coliform concentration dropped from 1.72×10^3 to 0.9 organisms per gram of dry alfalfa within 24 hr after irrigation stopped and the alfalfa was exposed to bright sunlight for 10 hr. Die-off experiments showed that Salmonella strains had identical survival characteristics to fecal coliform indicator organisms, while others were substantially less resistant. These observations coupled with the close phylogenetic relationship between Salmonella and fecal coliform (E. coli) suggest that it is valid to use fecal coliform survival rate as an indicator of Salmonella survival. (8)

Another 2-year study to determine the movement of total coliform and fecal coliform in soil indicated that total coliform and fecal coliform from septic tank effluent, which normally moved horizontally, decreased significantly with horizontal distance and depth. A conclusion based on the study is that it seems unlikely that coliform bacteria would move into the permanent groundwater system; and reduction in the number of coliform was probably a result of soil filtration and die-off. However, the possibility of slight groundwater contamination by vertical movement did exist. (116)

In another experiment the survival characteristics of total coliform, fecal coliform, and fecal Streptococci were investigated under natural conditions in ice-covered water at 0°C. (42) It was found that after 7.1 days (mean flow time between sampling stations), and a distance of 317 km, the relative survival rate was total coliform < fecal coliform < fecal Streptococcus, with 8.4, 15.7, and 32.8% of the initial populations remaining viable, respectively. The most rapid die-off was found to occur during the first 1.9 days. It was also observed that there is a continuing need for better pathogenic indicators because a quantitative relationship does not exist between coliforms and enteric pathogens. This makes it difficult to interpret results relative to potential health hazards and confirms that there is a need to assay potentially hazardous enteric microorganisms to assess the "real" health hazard.

Relating this to wastewater treatment plants, sanitary landfills, and refuse handling/disposal, it may not be good practice to make judgments regarding potential health hazards based solely on the presence of total or fecal coliforms. Air and solid wastes are different media compared to water, so interpretations based on the presence of coliform may not apply to airborne and solid waste sampling.

In another experiment, viruses were recovered from a sanitary landfill on the 2nd and 3rd week of leachate production at which time the number of pfu/liter reached 40 to 690, respectively, while the control showed only 100 pfu/liter after the 3rd week. No further positive results were obtained after the 3rd week. (22) It appeared that leachate from the sanitary landfill and open dump was toxic to the viruses and the author indicates that failure to isolate viruses may be due to the inhibition of virus-host cell interaction or association of viruses with leachate solids.

In other experiments, viruses from dump leachate were recovered when EDTA was added to the leachate. The author suggests that this may be due to release of viruses in suspension by EDTA. (22) In this research, it was found that coliform concentration in the leachates declined relatively rapidly with time for the sanitary landfill compared to an open dump. According to the author, (22) identical counts of total coliform and fecal coliform, in leachates, indicate the presence of large amounts of fecal materials in the solid waste. The conclusion drawn by the author of this study, regarding the survival of viruses in leachate from sanitary landfills and open dumps, was that they do possess the ability to survive and more importantly, the leachates did not have any detrimental effects on polio viruses.

Aerosolized Microorganisms

Of particular interest in this study is the transmission and ingestion of aerosolized microorganisms. According to Langmuir, (51) airborne infection generally involves the inhalation of droplet nuclei resulting from the evaporation of aerosol droplets (see Table I-7) which remain suspended for relatively long periods of time. Organisms within particles of a heterogeneous aerosol do not distribute themselves evenly throughout the droplets. The distribution of organisms throughout the available particles of the aerosol is influenced by the concentration of organisms in the material aerosolized. The smaller particles of the aerosol remain unpopulated at low organism concentrations whereas at higher concentrations the smaller particles of the aerosol contain

TABLE I-7. DROPLET EVAPORATION RATES (135)

Droplet diameter (µm)	Evaporation time[a] (sec)
200	5.2
100	1.3
50	0.31
25	0.08
12	0.02

[a] At 22°C and 50% RH.

relatively larger numbers of organisms. Further, many workers have demonstrated that LD_{50} or ID_{50} values of certain airborne pathogens decrease as the aerosol particle size increases.

Airborne particles bearing pathogens or "droplets" which are larger in size fall to the ground within a short time, but the smaller ones evaporate almost instantly, leaving "droplet nuclei," which incorporate any organisms originally present in the parent droplet. Droplet nuclei may remain suspended indefinitely, until removed by ventilation. (122)

The particles of most pathological interest are those which penetrate to and are deposited in the pulmonary spaces. Figure I-2 shows the deposition versus particle size of inhaled particles in the respiratory tracts and in the lungs of guinea pigs and monkeys compared with man. It has been found experimentally that the particulate removal efficiency of the guinea pig and monkey lungs is not significantly different from man. (63)

Between 1 and 2 μ there is a maximum percentage penetration and deposition in the pulmonary spaces. Larger particles are deposited in the lungs to a lesser extent because they are trapped higher up in the respiratory tract. Lung deposition of finer particles falls off as particle size goes below 2 μ and then rises again below 0.5 μ. (63) The highest probability of deposition in the pulmonary air spaces occurs with 2 μ particles as derived from the combined probabilities of deposition at various depths in the respiratory system for a unit-density spherical particle.

Hatch (63) indicates that a quantitative understanding of the relationship between the dose of an inhaled aerosol and the kind and degree of response clearly requires that the magnitude of the dose be expressed in terms of effective rates at the critical sites within the body where tissue response is initiated. It is not merely enough to know the atmospheric concentration and the volumetric flow rate of breathing. The product of these two simply gives the rate of delivery of the aerosol into the respiratory system.

The health risk, according to Hatch, (3) resulting from the deposition of toxic or infectious particles within the respiratory system is not necessarily proportional to the total quantity of particles trapped. For some diseases, the risk varies depending on the site of deposition within the system, and, in certain cases, there will be no risk whatever unless particles are deposited at particular sites. Further, for a full understanding of the importance of the dust trapping characteristics of the respiratory system in disease etiology, the knowledge of the overall efficiency of respiratory deposition in relation to particle size and to the dynamics of air flow is not enough. Such relationships must be established for different sites at various depths within the system taking into account the fact that a particle will penetrate that depth, as well as upon the efficiency of trapping at the site in question.

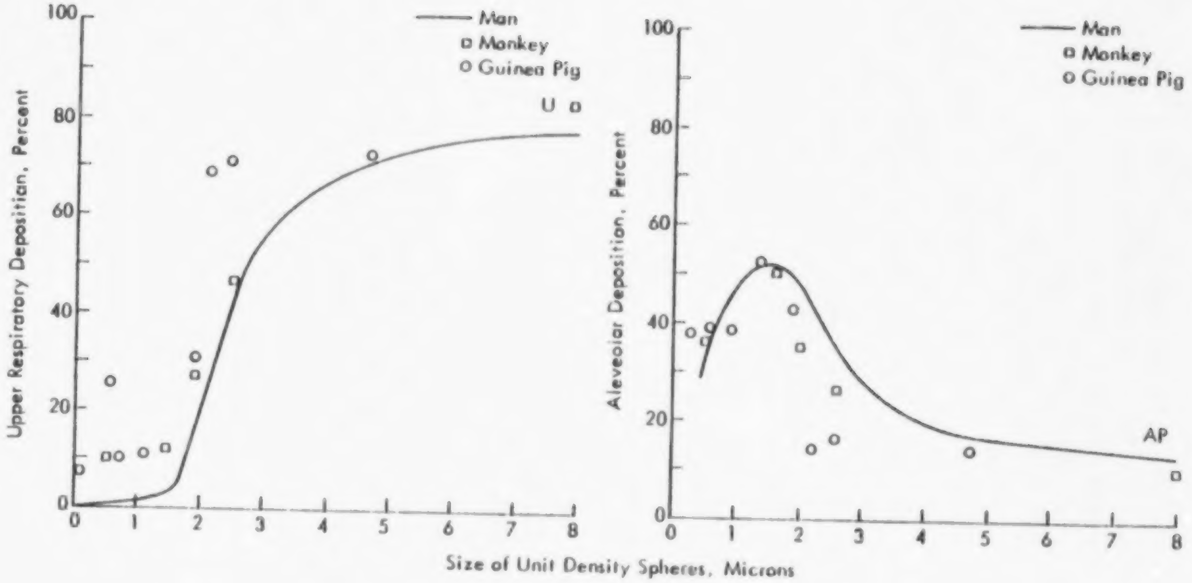

Figure I-2. Deposition versus particle size of inhaled particles in the upper respiratory tract and in the lungs of the guinea pig and monkey compared with man. (63)

The human body has developed a remarkable system of defense against the invasion of microorganisms. The first line of defense against microorganisms is the complex of anatomic and chemical barriers produced by external and internal body surfaces. (71)

The deposition sites for airborne microorganisms usually will be (a) the nose--which is an effective filter, (b) the larynx--where the dynamics of airflow will determine the deposition of microorganisms, and (c) airways. Although the landing sites are smaller in a child, the hydrodynamics of the air passages are similar; thus, penetration of an aerosol will be similar in the child and the adult.

If an aerosol of bacteria or virus particles is inhaled, it will be deposited throughout all sections of the respiratory tract; however, the fate of the deposited microorganism will depend on their specific landing site. Experimental studies on animals have shown that virulent microorganisms which deposited in the lung were rapidly rendered nonviable. The number of viable E. coli cells declined very rapidly in the airways and in the lungs of guinea pigs. The dead E. coli cells were found to behave like inert particles undergoing pulmonary clearance by mechanical mucous transport. (122)

The death rate of airborne microorganisms is a function of many variables including cellular physiological differences, relative humidity, temperature, oxygen concentration, light, and air pollutants. Depending upon the quality and quantity of these factors, the death rate may increase or decrease. (85)

Because of the lack of data on death rate in the natural environment, it is assumed that laboratory measured values will roughly approximate mean death rates in a dynamically changing atmosphere. (85)

It is suggested by Lighthart et al. (85) that an atmospheric diffusion model from a point source can be applied (Pasquill inert material dispersion model) with a modification for biological death (BD). Knowing a BD constant for various specific atmospheric conditions, the modified model gives the concentration of microorganisms as a function of the distance from the source having some effective source height.

During his experimental studies, Fannin (40) determined downwind concentrations of airborne coliphages from a wastewater treatment plant. He did not find any apparent effects of sunlight, wind speed, relative humidity, and temperature on the downwind concentration of coliphages.

Studies conducted by Hyslop (70) on poliomyelitis and bronchitis viruses indicate that there is a probability of disease being spread by air. However, the viability of such airborne organisms declines progressively as a result of physical and other factors. Relative humidity strongly influenced viability in the experimental studies with some strains of virus more sensitive to Rh than others. The infectivity of polio virus at 75% RH regressed after the virus became airborne. (70)

Experiments (70) indicated that relatively small amounts of virus were detected after nebulization of high-titre suspensions, which suggests that mortality must have been very great during the first 2 min in aerial suspension. There were several factors, such as rapid desiccation, oxidation, impaction, shearing, changes in osmotic and atmospheric pressure, contact with metals, and other toxic chemicals which contributed to losses occurring during the aerosol sampling, according to the author. Other experimental results indicate that even when aerosols of high initial titre are generated in an enclosed space, regression of infectivity is so rapid that the "cloud" should become virtually noninfective within a few hours. (70)

Webb (147) states that the removal of the most firmly held water molecules from bacteria results in some loss of viability, especially in air. His studies disclosed that only 0.01% of an aerosolized initial cell concentration remained viable for 48 hr or longer. Webb also found that death of aerosolized bacteria occurs in two stages, a rapid initial kill during the first second, and a subsequent slower death. (147)

A rapid death rate for E. coli has been observed in experimental studies. (122) After a few seconds only 10% of the organisms remained viable. At a relative humidity of 50 to 60% and a temperature of 25°C, only 20% of the cells remained viable after the first 0.3 min.

According to some researchers, the particle size of airborne microorganisms (i.e., droplet, droplet nuclei, or dust particles) markedly affects viability. Also, the cloud age of aerosolized microorganisms affects both viability and infectivity. (112) Table I-8 indicates the effect of cloud age on LD_{50} and Figure I-3 shows the survival of airborne bacteria as a function of aerosol (cloud) age. (16)

TABLE I-8. EFFECT OF CLOUD AGE ON INFECTIVITY (65)

	Cloud age (min)		
	60	120	180
LD_{50} cells	36	288	2,394

E. coli, because it is used as an indicator of pathogens, is of special interest. Studies have shown that survival of airborne E. coli cells, under

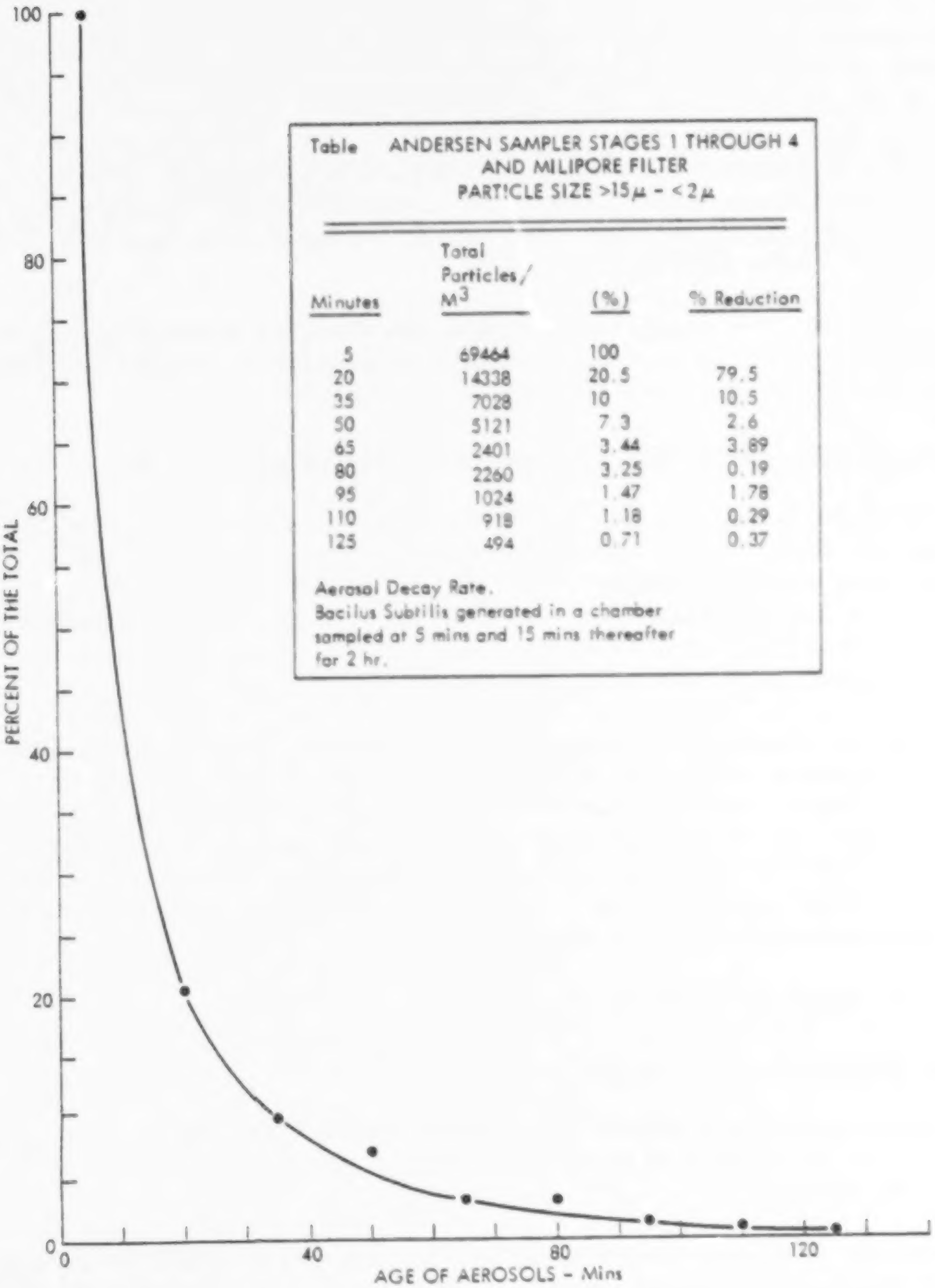

Table ANDERSEN SAMPLER STAGES 1 THROUGH 4 AND MILIPORE FILTER PARTICLE SIZE >15μ - <2μ

Minutes	Total Particles/M^3	(%)	% Reduction
5	69464	100	
20	14338	20.5	79.5
35	7028	10	10.5
50	5121	7.3	2.6
65	2401	3.44	3.89
80	2260	3.25	0.19
95	1024	1.47	1.78
110	918	1.18	0.29
125	494	0.71	0.37

Aerosol Decay Rate.
Bacilus Subtilis generated in a chamber sampled at 5 mins and 15 mins thereafter for 2 hr.

Figure I-3. Survival of airborne bacteria as a function of aerosol age. (16)

conditions of environmental stress, is directly related to particle size. (122) The loss of viability of E. coli contained in larger particles was much less than in smaller particles. It also was found that the rate of loss of viability of E. coli disseminated in 1 μm particles often exceeded 10%/min in open air at night under normal humidity conditions, compared with only a few percent per hour in an enclosed space. The same effect was observed with Staphylococcus epidermidis and Staphylocci group C. This effect was termed the "open air factor" (OAF). (112)

In general, the death rate of aerosolized microorganisms in dust particles increases with an increase in humidity and with illumination, both natural (solar) and artificial.

Specific Dose/Response Relationships for Various Microorganisms

Table I-9 summarizes the specific dose/response relationships disclosed by this literature study. Several caveats are in order here. The time lag in assessing the potential health impact of an etiological factor is a main obstacle in the evaluation and documentation of data. Also, current mechanisms for obtaining epidemiological data are inadequate, according to the Task Force Report on Respiratory Diseases. (120)

Because defensive mechanisms are very complex, animals like guinea pigs, squirrel monkeys, etc., used in laboratories may or may not yield data applicable to humans. Further, different researchers use different experimental methodology. The effects of viral infection followed by bacterial infection and vice versa are extremely difficult to identify. Also, it is difficult to determine their combined effect, if any, or to separate short-range effects from long-range effects.

SURVEY OF SPECIFIC INDUSTRIES

Refuse Collection and Handling

Solid wastes vary within each country because both the quantity and composition are determined by social customs and standards of living in each region considered.

Efforts were made by the World Health Organization (WHO) in 1971 and the United States Public Health Service (USPHS) in 1968 to collect data on solid waste handling and disposal industries on an international and national basis, respectively.

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TABLE 1-9. SPECIFIC DOSE/RESPONSE RELATIONSHIPS FOR VARIOUS MICROORGANISMS AND SUBJECTS

Reference Number	Subject	Organism	Dose	How administered	Response	Remarks
26	Guinea pigs	B. Anthracis	15,000 org. < 1 µm	inhalation	LD_{50}	Experiment designed to show relation of aerosol particle size to LD_{50}.
26	Guinea pigs	B. Anthracis	60,000 org. < 3 µm	inhalation	LD_{50}	
26	Guinea pigs	B. Anthracis	400,000 org. < 7 µm	inhalation	LD_{50}	
26	Guinea pigs	B. Anthracis	900,000 org. < 11 µm	inhalation	LD_{50}	
56	Guinea pigs	P. Tularensis	1 org. 1 µm	inhalation	LD_{50}	Experiment designed to show relation of aerosol particle size to LD_{50}.
56	Guinea pigs	P. Tularensis	6,500 org. 7 µm	inhalation	LD_{50}	
56	Guinea pigs	P. Tularensis	20,000 org. 12 µm	inhalation	LD_{50}	
56	Guinea pigs	P. Tularensis	170,000 org. 22 µm	inhalation	LD_{50}	
56	Rhesus monkeys	P. Tularensis	17 org. 1 µm	inhalation	LD_{50}	Experiment designed to show relation of aerosol particle size to LD_{50}.
56	Rhesus monkeys	P. Tularensis	240 org. 7 µm	inhalation	LD_{50}	
56	Rhesus monkeys	P. Tularensis	540 org. 12 µm	inhalation	LD_{50}	
56	Rhesus monkeys	P. Tularensis	3,000 org. 22 µm	inhalation	LD_{50}	
97	Human	Typhoid	10^3 org.	oral	no infection	
97	Human	Typhoid	10^7 org.	oral	ID_{50}	
97	Human	Shigella	10 org.	oral	infection	
97	Human	Typhoid and other salmonellae	10^5 org.	oral	infection	
88	Human	E. Coli or V. Cholerae	10^8 org.	oral	infection	
88	Human	Salmonellae and S. Typhae	10^5 org.	oral	infection	
88	Human	Shigella	10 to 100 org.	oral	infection	
31	Pig	Total count	1.3 x 10^3 to 3.5 x 10^5 colony forming plates per m^3 (CFP)	inhalation	no infection	
31	Pig	Fecal Coliform	1.9 x 10^1 to 2.6 x 10^1 CFP	inhalation	no infection	
112	Human	Polio virus	200 PFU	oral	100% infection	
112	Human	Polio virus	20 PFU	oral	100% infection	
112	Human	Polio virus	2 PFU	oral	< 66% infection	
112	Human	Polio virus	0.2 PFU	oral	0% infection	
112	Human infants	Polio virus	100 TCD_{50} to 1,000 TCD_{50}	oral	100% infection	
112	Human infants	Polio virus	10 TCD_{50} to 100 TCD_{50}	oral	77% infection	
112	Human infants	Polio virus	10 TCD_{50}	oral	66% infection	

(continued)

TABLE I-9 (continued)

Reference Number	Subject	Organism	Dose	How administered	Response	Remarks
112	Mice	Coxsaic viruses	30 TCD_{50}	inhalation	infection	
112	Mice	Coxsaic viruses	18 TCD_{50}	inhalation	infection	
62	Human	Coxsaic viruses	100 TCD_{50}	intranasally	50% infection	
62	Human	Coxsaic viruses	50 $TCD_{50} < 3\mu$	inhalation	70% infection 100% respiratory infections	
62	Human	Adenoviruses	1,000 TCD_{50}	transmitted by upper respiratory tract	infection	
112	Human	Infectious hepatitis	0.1 g of feces from the infected patients	oral	infection	
112	Human	Infectious hepatitis	0.01 g of feces from the infected patients	oral	no infection	
112	Hamster	Influenza and para-influenza	320 TCD_{50}	aerosolized	100% infection	
112	Hamster	Influenza and para-influenza	32 TCD_{50}	aerosolized	100% infection	
112	Hamster	Influenza and para-influenza	3.2 TCD_{50}	aerosolized	67% infection	
112	Hamster	Influenza and para-influenza	0.3 TCD_{50}	aerosolized	33% infection	
112	Hamster	Influenza and para-influenza	0.03 TCD_{50}	aerosolized	no infection	
112	Egg	Influenza and para-influenza	5 EID_{50}	injection	infection	EID = Egg Infective Dose
112	Egg	Influenza and para-influenza	0.45 EID_{50}	injection	infection	
112	Human	Parainfluenza	100 TCD_{50}	internasal injection	65% infection	
112	Human	Parainfluenza	80 TCD_{50}	internasal injection	75% infection	
112	Human	Parainfluenza	1.5 TCD_{50}	internasal injection	100% infection	
112	Human	Parainfluenza	15 TCD_{50}	internasal injection	no infection	
112	Human	Parainfluenza	2,000 TCD_{50}	internasal injection	no infection	
112	Human	Parainfluenza	20,000 TCD_{50}	internasal injection	infection	
112	Human	Rhinoviruses	30 to 10,000 TCD_{50}	internasal injection	not given	
112	Human	Rhinoviruses	< 1 TCD_{50}	internasal injection	40% infection	
112	Human	Rhinoviruses	16 TCD_{50}	internasal injection	not given	
112	Human	Measle virus	10 TCD_{50}	intranasal spray	89% infection	
112	Human	Measle virus	6 TCD_{50}	intranasal spray	69% infection	
112	Human	Measle virus	2 TCD_{50}	intranasal spray	49% infection	
112	Human	Measle virus	1 TCD_{50}	intranasal spray	23% infection	
112	Human	Measle virus	0.6 TCD_{50}	intranasal spray	$>$ 12% infection	
112	Human	Measle virus	0.2 TCD_{50}	intranasal spray	$>$ 14% infection	
112	Human	Measle virus	0.1 TCD_{50}	intranasal spray	no infection	

(continued)

TABLE I-9 (continued)

Reference Number	Subject	Organism	Dose	How administered	Response	Remarks
112	Human	Polio virus	2 PFU	oral	70% infection	
112	Human	Polio virus	20 PFU	oral	100% infection	
112	Human	Polio virus	100 TCD_{50}	oral	infection	
112	Human	Polio virus	10 TCD_{50}	oral	infection	
112	Human	Coxsackie	18 TCD_{50}	Respiratory route	infection	
112	Human	Coxsackie	1.5 TCD_{50}	Respiratory route	infection	
112	Human	Adenovirus	<150 TCD_{50}	Respiratory route	infection	
112	Human	Parainfluenza	0.5 TCD_{50}	Respiratory route	infection	
112	Human	Parainfluenza	1.5 TCD_{50}	Respiratory route	infection	
112	Human	Parainfluenza	2,000 to 20,000 TCD_{50}	Respiratory route	infection	
112	Human	Influenza	790 TCD_{50}	Respiratory route	infection	
112	Human	Measles	15 TCD_{50}	Respiratory route	infection	

Main efforts by WHO were in the following areas: (138)

1. To ascertain the impact of health and socioeconomic factors of improper handling of solid wastes.

2. To appraise current practices in solid waste industries.

3. To identify areas of future action.

A private survey indicates that the amount of organics in municipal waste is increasing while the amount of inorganics is decreasing. Total organics were 45.0% in 1939, but were 72.0% in 1972. Inorganics decreased to 28% from 55% during the same period. (76)

The physical characteristics of solid wastes vary considerably (see Table I-10).

TABLE I-10. COMPOSITION OF SOLID WASTE (138)

	Range of values (excluding industrial wastes)
Per capita weight (kg/day)	0.2-3.0
Density (kg/m^3)	100-500
Putrescible matter (%)	5-90
Paper (%)	0.25-55
Plastics (%)	0.1-7.0

The results of a survey conducted by USPHS is presented in Table I-11. The first three items (paper, garbage, and leaves and grass) constitute organics which may be a source of microorganisms.

WHO focused its attention on the potential health problems arising from solid waste handling and disposal. They concluded that limited studies have been made on the direct effects of handling solid wastes, but evidence shows that improper handling adversely affects health and welfare of the workers and the community. According to the committee, it is possible that in the long range it may affect the food chain.

The WHO group did investigate epidemiological data. A quotation from their report is as follows: "A study in India of stool specimens from refuse workers indicated that 94% of this group were infected with selected parasites as against slightly more than 4% in the control group." The same study

TABLE I-11. PHYSICAL CHARACTERISTICS OF MUNICIPAL REFUSE (60)

Item	% (wet basis)	% (dry basis)
Paper	48.0	35.0
Garbage	16.0	8.0
Leaves and grass	9.0	5.0
Wood	2.0	1.5
Synthetics	2.0	2.0
Cloth	1.0	0.5
Noncombustibles		
Glass	6.0	6.0
Metals	8.0	8.0
Ashes, stone, dust, etc.	8.0	6.0

Chemical characteristics

Measure	Minimum	Maximum	Average
Percent moisture	20	60	38
Percent carbon (wet)	8	35	24
Percent nitrogen (wet)	0.2	3.0	1.0
kJ/kg (wet)	6,978	13,956	10,467
Ash percent (dry)	4	9	6.5
Carbon percent (dry)	20	50	40
Nitrogen percent (dry)	0.3	5	1
kJ/kg (dry)	13,956	23,260	17,910

indicated that the infection rate with worms and related organisms was three times that of the control group. Contamination of this kind is liable to occur at all points where waste is handled. However, although it is certain that vector insects and rodents can transmit various pathogenic agents of disease, it is often difficult to demonstrate a precise relationship between a source of infection, and the population infected.

The USPHS survey was composed of about 75% urban population with the rest rural. (60) Its purpose was to gain insight in the following areas: (a) collection and disposal systems; (b) labor; (c) equipment; (d) quantities; and (e) financial aspects. There was no approach to health problems.

The WHO committee and the Office of Solid Waste Management both found that very little comprehensive data are available because (a) solid waste is heterogeneous in nature and varies seasonally, which makes measurements and categorization difficult, and (b) there is no standardized approach for the collection of necessary data, either nationally or internationally.

The situation is further complicated by the interchanging use of the terms "refuse," "garbage," and "rubbish." It will be convenient to adopt the WHO nomenclature of two main categories: fermentable organic wastes, which decompose rapidly; and nonfermentable wastes, which resist decomposition or decompose very slowly. (138) Wastes in the first category arise primarily from food for human consumption. Nonputrescible waste, the second category, consists mainly of paper, tin cans, glass, wood, plastics, etc. There is a need to standardize terms before meaningful data on potential health aspects can be collected. According to statistics, domestic and industrial wastes amount to between 2.3 and 2.7 kg/person/day. (60) The average is about 2.4 kg/person/day, and is moving upward. However, volume per person in 1951 was more than in 1970. The reasons for decline in volume were increased use of frozen packaged goods and other highly processed and prepared food. (125) Papers, paper containers, cans, and bottles are also on the increase. The density of this collected material varies from approximately 148 to 386 kg/m^3, depending on composition.

According to WHO, ideal solid waste should not contain any fecal matter or urine. Disposable diapers are a special problem in the western world and especially in the United States. Also, there is a problem of household waste being contaminated with fecal matter from pets. WHO feels that pathogenic organisms will be found in domestic wastes in spite of any stringent measures such as prohibiting fecal matter in domestic waste, and prohibiting mixing of hospital, slaughterhouse, and other hazardous wastes with domestic waste.

It is estimated that, nationally, about 337,000 people (7,60) are employed in the waste handling and disposal industry. Waste in the urban areas amounts to approximately 2.59 kg/capita/day, and 1.37 kg/capita/day in rural areas. (60) Collection frequently varies from no collection to twice per week.

According to Parrakova (73) refuse is an excellent medium in which pathogenic microorganisms survive, as do intestinal parasites in certain life stages (see Table 12). In contrast, Knoll (72) of Germany indicates that urban refuse normally contains no particularly injurious elements from the standpoint of epidemiology and hygiene. In Germany, infections and occupational diseases among refuse workers are almost unknown, even for those individuals in manual sorting of the raw refuse. Further, according to Knoll, raw refuse is not dangerous but rather may possess bacteriostatic or bacteriocidal activity. Such contradictory views are not unknown in the area of potential health effects of refuse.

TABLE I-12. CONCENTRATION OF MICROORGANISMS (47)

	Total coliform[a]	Fecal coliform[a]	Fecal Streptococci[a]	Salmonella Shigella[a]
Refuse	10^8[b]	10^7-10^8	10^6	Very negligible
Sewage sludge	10^8[b]	10^8	10^4	-
Refuse sludge	10^8[b]	10^7-10^8	10^6	-

a/ Bacterial count per gram dry weight.

b/ All units in MPN.

Cimino has shown that the incidence of acute respiratory conditions for New York City Sanitation Department workers does not exceed that of the general population. (109) In the American Journal of Public Health, 1975, he reported an incidence of 990 acute respiratory conditions per 1,000 workers per year as compared to 950 for the general population. The inference is that there is no discernible health risk from aerosolized microorganisms.

A study at a plant for refuse grinding prior to composting was designed to determine aerosolized microorganism concentrations at various points within the plant. (3) The heaviest concentration was found at the "ground waste transfer" where, based on 25.92 m^3 normal lung respiration in 8 hr, a worker would ingest approximately 135,000 microbes in a shift. No specific health hazards were stated.

In another investigation of an incinerator plant (10,37) it was found that there were 10,200 to 25,400 viable microorganisms per cubic meter of air around the dumping and charging area. This measurement was taken 1.5 m above floor level and corresponds to 2,600,000 to 6,600,000 cells ingested in an 8-hr shift.

The health effects of solid waste handling and disposal are partly determined by the chances of survival of pathogens in solid waste and the conditions under which they can or cannot survive. Studies have been conducted along this line and they represent several views. A study conducted on the end product of refuse-sewage sludge composting by windrow process (47) indicated:

1. Salmonella and Shigella were present in raw refuse and sewage sludge in relatively small numbers. Those pathogenic enteric bacilli that were originally present or inserted under controlled conditions, disappeared within 7 to 12 days.

2. Polio virus (Type 2) inserted into the windrow were inactivated after 3 to 7 days' exposure at 49°C.

3. Insertion techniques indicate that pathogenic fungi did not survive composting temperatures.

4. Insertion studies indicated the *Mycobacterium tuberculosis* was destroyed within 2 weeks.

The study further indicates that fewer pathogens survive aerobic conditions in refuse, in comparison with anaerobic conditions. This may imply that diffusion of air at very low flow rates through refuse to maintain aerobic conditions might help to reduce the number of pathogens that survive.

Other factors also may be of importance in the suitability of refuse as a medium of growth for pathogens. Insertion studies indicate that the number and growth of pathogens diminish continuously in refuse but examination of compost at later dates indicates that coliforms reappear. (47)

Wastewater Treatment and its Spray Irrigation

Table I-13 gives a list of some bacteria and viruses found in sewage. It is necessary to consider that a complete account of any microbial population of the complexity found in sludge is rarely possible, and the same is true for solid wastes. For this reason, the coli group of bacteria is used as indicators to demonstrate the presence of pathogens (fecal material of human origin). Recently, fecal Streptococci have been used as an indicator of bovine fecal sources. The coliform bacilli indicator group consists of *E. coli*, *Aerobacter aerogenes*, and *Klebsiella pneumoniae*. All these are pathogenic only under special conditions, (11) and they fall under the general category of enterobacilli.

TABLE I-13. BACTERIA AND VIRUS FOUND IN SEWAGE

Bacteria		Enteric virus
Aerobacter aerogenes	*Flavobacterium aquatile*	Infectious hepatitis
Aerobacter cloacae	*Flavobacterium* sp.	Coxsackie, Group A
Achromobacter sp.	*Micrococcus* sp.	Coxsackie, Group B
Alcaligenes sp.	*Proteus inconstans*	Polio virus
Brevibacterium sp.	*Proteus morganii*	Adenovirus
Bacillus cereus	*Pseudomonas aeruginosa*	Echovirus
Bacillus megaterium	*Pseudomonas fluorescens*	Reovirus
Bacillus subtilis	*Pseudomonas ovalis*	
Bacillus sp.	*Pseudomonas* sp.	
Corynebacterium sp.	*Pseudomonas* - *Alcaligenes* intermediates	
Escherichia coli	*Serratia marcescens*	
Escherichia freundii	*Xanthomonas* sp.	

According to Brock et al. (17) although coliform testing is the best procedure available for evaluating the safety of a water supply, it must be interpreted cautiously because a positive test does not always indicate human pollution. Further, E. coli added to a water supply will eventually die, whereas some other intestinal organisms potentially harmful to man, such as polio virus, may be longer-lived. Thus, a negative test (for E. coli is not an absolute assurance that a water supply is safe.

Some researchers have evaluated the ratio of enteric viruses (e.g., polio viruses) to coliform, and found that the ratio varies between 1:50,000 to 1:6,500 in sewage and polluted surface waters. (29)

The literature indicates that the presence of airborne pathogens is inferred from the presence of coliforms. Water and air being different media, it may be questionable whether coliforms (total or E. coli) can be used as an indicator of aerosolized pathogens. At present, it seems that water and wastewater pollution principles are being applied to airborne microorganisms.

During a microbiological investigation at a sewage treatment plant, Ehrlich (82) found that a worker ingested via respiration only 0.124% of the Klebsiella pneumoniae required to produce infection in squirrel monkeys. This resulted in part because workers were exposed to maximum concentrations of the pathogen only 1% of the working time. Also according to the author, more than half of the viable microorganisms from the plant were associated with particles greater than 6 µm in diameter and therefore would not be readily respirable.

Another investigation of a sewage treatment plant found that a man working within 1.5 m of the downwind edge of an aeration tank, at 4.5 m/sec windspeed will breathe one Klebsiella per two breaths, or 3,600 Klebsiella in 8 hr. (96)

This same investigation established a die-off rate for aerosolized microorganisms. It was found that colonies decreased from 1,000 to 10 in the final 2 sec. The maximum decay rate occurs between 0.7 and 1.0 sec with stabilization after 3 sec. However, despite the rapid die-off rate during the final 3 sec, the remaining population persisted for a considerable time and distance. (96)

Coliform counts on agar plates showed more than five colonies at a distance of 6.1 m from the activated sludge unit dropping to less than two colonies at 30.5 m. (96)

About 40% of the viable bacteria in the vicinity of the activated sludge units were associated with aerosol sizes that permit lung penetration. (96) The Entrobacteriacea that are potential pathogens of the respiratory tract (Klebsiella, Aerobacter, Proteus) were found to be more numerous than the enteric bacteria. (96) According to the author, coliform bacilli (E. coli, Aerobactera, Klebsiella pneumoniae) are potential health hazards. He found about 6% of Klebsiella airborne and considered them significant.

Hickey and Reist (66) calculated geometric mean diameters of viable cells recovered in the field adjacent to wastewater treatment plants. Results are presented in Table I-14.

They concluded the following:

1. The viable aerosols were clearly within the human respirable particle size range.

2. The geometric mean particle size of the viable aerosol seemed to diminish initially after generation but did not change appreciably afterward.

3. The geometric mean particle size of the downwind viable aerosol may be smaller than that of the upwind aerosol.

4. Protein-bearing aerosols (may be an allergy producing air pollutant) were also in the human respirable range and were considerably larger than nonprotein-bearing particulate aerosols.

During their literature search, on which the above conclusions were based, they found that concentrations of viable cells may be as high as 1,170 per cubic foot (41,200/m^3). These cells remain viable even at the lowest concentration of five to 10 cells per cubic foot (175 to 350/m^3). These aerosols are clearly in the human respirable range and may be retained by the lower respiratory tract.

Concern has been shown by several researchers regarding the public health aspects of land application of wastewater. However, in the United States the potential health hazard associated with the application of wastewater to the land is low, and in fact, is less than that associated with the discharge to subsurface waters. (126)

The health hazards of working around and handling wastewater on land application sites are minimal. It has been emphasized that with reasonable habits of personal hygiene, the health hazards appear to be no different than for activated sludge and trickling filter plants. It is concluded that sewage effluent is not hazardous to personnel and that overall health risks are not higher for operators than for the public at large. (79)

Several investigators have measured concentrations of aerosolized microorganisms arising from irrigation with wastewater. (23,24) Table I-15 summarizes their results.

TABLE I-14. PARTICLE SIZES OF AEROSOLS ASSOCIATED WITH AERATED WASTEWATER PROCESSES (66)

Wastewater processes	Type of aerosol	Distance downwind from source (m)	Geometric mean diameter of aerosol (μ)	Geometric standard deviation
Activated sludge aeration tank	Viable bacteria	0	7.0	2.0
		0.9-30.5	4.3-5.1	1.8-2.6
		15.2	5.8	1.9
		30.5-42.7	6.2	1.9
		Upwind	7.8	3.2
		Inside enclosed tank	5-10	
		Air discharge stack of enclosed tank	3.2	1.9
	Protein-bearing particles	0	40% < 10 (mean = 11.8)	
		0-60.9	2.6	2.4[a]
		Upwind	4.1	1.9[a]
	Protein and nonprotein-bearing particles	0-60.9	0.25-0.33	2.5-2.7[a]
		Upwind	0.16-0.28	2.3-3.1[a]
Trickling filter	Viable bacteria	Various	4.2-4.5	2.0
Simulated aerated wastewater (mg/ℓ of solids)	Viable bacteria			
0		0	3.7-5.7	[a]
40		0	2.8-3.1	[a]
130-260		0	4.8-5.8	[a]
400-1,600			2.4-8.6 (mean = 5.0)	[a]

[a] Values from median diameters.

Note: Particle sizes of viable bacterial aerosols are aerodynamic equivalent geometric mean particle diameters.

TABLE I-15. BACTERIAL LEVELS RESULTING FROM IRRIGATION WITH WASTEWATER

Organism	Distance from source (m)	Concentration (organisms/m^3)
Aerosolized coliform (75)	10	0-490
Aerosolized coliform	20	-
Aerosolized coliform	60	4-503
Aerosolized coliform	70	-
Aerosolized coliform	100	0-88
Aerosolized coliform	150	0-32
Aerosolized coliform	200	0-25
Aerosolized coliform	250	0-17
Aerosolized coliform	300	0-4
Aerosolized coliform	350	0-4
Aerosolized coliform	400	0
Total aerobic (141)	Upwind	28
Total aerobic	47	1,630
Total aerobic	152	100
Coliformlike	Upwind	2.4
Coliformlike	47	330
Coliformlike	152	30

Lepmann (75) found that individual workers, at a distance of 100 m from the source, will breathe 36 coliform bacteria in 10 min. Coliforms were found 70 m downwind and at 350 m downwind. According to the author, organic matter present in the spray water effluent protects aerosolized E. coli which may be an important health aspect. At a downwind distance of 60 m, only one colony of Salmonella was found. The author did not present any supporting evidence of infection.

Sovler (141) found that the ratio of viable cells per cubic meter of air to viable cells per milliliter of wastewater spray decreased with aerosol age, but the mass median diameter of viable particles increased with aerosol age. The mean aerosol reduction of 47 m from the source was 96.8% for total aerobic bacteria.

Aerosolized microorganism levels produced depend on (a) viable microorganisms in wastewater, (b) aerosolization efficiency, and (c) wind speed.

CONTROLS AND PROTECTION

General Discussion

Most of the control measures described here will be suitable for an enclosed space where aerosolized microorganisms are present in relatively high concentrations. The purpose of these controls is to minimize the potential risk that a worker might face in solid waste handling and disposal facilities. It is assumed that aerosolized microorganisms are generally attached to dust particles, droplets, or droplet nuclei.

The proximity of man to any system designed to kill microorganisms complicates decontamination. Due to the absence of quantitative data that relate a minimal concentration level to the probable risk, (124) several control techniques might have to be applied. The approach, therefore, should be to apply the "Best Available Technology" (BAT) or "Best Practical Technology" (BPT). The following qualitative assumptions are implicit in the discussions that follow:

1. Man and microorganisms are ubiquitous.

2. Each individual is different in terms of susceptibility to pathogenic microorganisms.

3. Airborne concentrations and species of microorganisms may vary widely from plant to plant.

4. The survival of airborne microorganisms is a complex phenomenon.

Control techniques for removal of, or protection against, an aerosolized population in an enclosed space are:

1. Ventilation;

2. Irradiation with UV light;

3. Personal worker protection (i.e., vaccination, protective devices); and

4. Administrative controls.

Microbial contamination controls should be on a continuing, consistent, logical, and defensible basis. The higher the degree of risk, the greater should be the emphasis on control techniques, personnel training, reliability, and maintenance of the systems used. (33)

A definition of the problem and a subsequent control system design must take into account: (33,122)

1. The specific microorganisms concerned.

2. The concentration at the place concerned.

3. The establishment of contamination control criteria (only aerosolized microorganisms attached to dust particles, droplets, or droplet nuclei are considered).

4. Management imposition of personal hygiene rules, mandatory vaccinations, use of protective devices, etc.

5. Air sampling feedback to determine the effectiveness of control. Instantaneous measurement devices may be applied to find peak concentrations.

Ventilation--

Aerosolized particulates containing viral and bacterial pathogens play an important role in determining the atmospheric spread of infectious diseases. The settling velocity of airborne particles, therefore, is of importance. Because of the tendency of dust to settle, dust-borne infection is associated with specific places (i.e., settled dust may form an external reservoir of infection). In this case, no chain of infections separated by an incubation period is to be expected. (122)

Droplet nuclei-borne infections are not associated with epidemiologically important external reservoirs of infection. Because of their small size, these particles are generally dispersed throughout indoor atmospheres and are generally removed by ventilation, as shown above. (22,124) Droplet nuclei are aerodynamically suited to reach susceptible tissue deep within the respiratory tract. (122)

Figure I-4 shows the effectiveness of ventilation in removing these small particles. (4) Under ordinary conditions of ventilation, with three air changes per hour, two-thirds of the 13 μ particles deentrained from the room atmosphere would be removed by settling and one-third by ventilation, whereas the removal of droplet nuclei ($\sim$2 to 3 μm) would be accomplished only by ventilation. Thus, risk is mainly restricted to finer particles. (63)

Ultraviolet Irradiation--

Ultraviolet irradiation is amazingly effective in killing organisms suspended in the air as droplet nuclei. Table I-16 shows the relative vulnerability of individual cells to UV radiation.

Either direct irradiation of room air or irradiation of upper air only may be employed, but personnel protection is needed for the former. (124) Using special wall fixtures, UV can be directed across the room above head

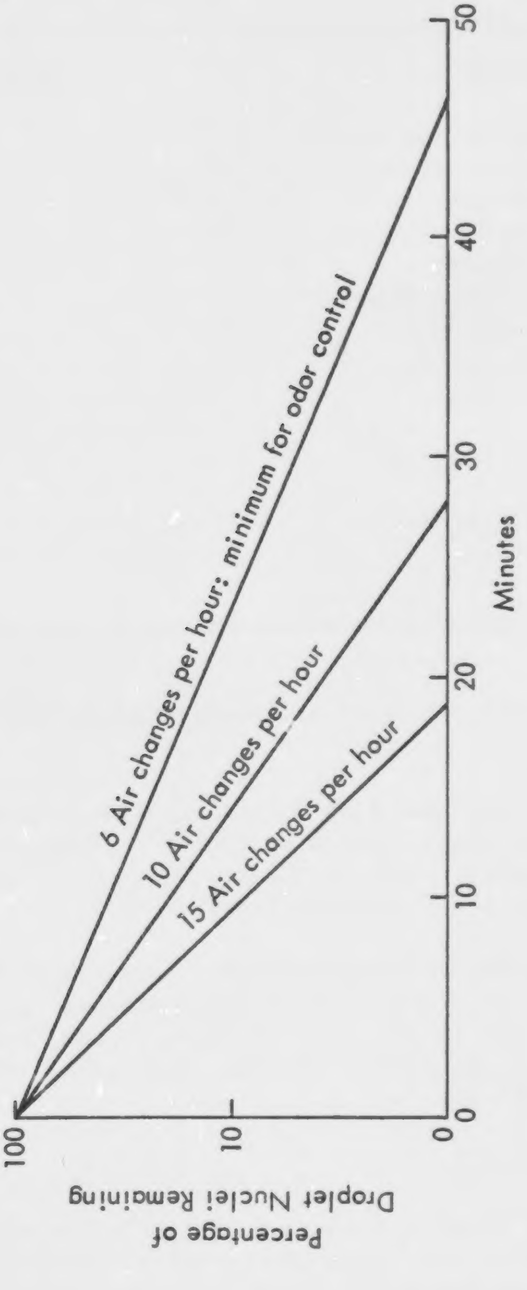

Figure I-4. Effectiveness of ventilation in removing small particles. (122)

TABLE I-16. RELATIVE VULNERABILITY OF INDIVIDUAL CELLS TO ULTRAVIOLET RADIATION IN THE 2.537×10^{-7} M WAVE BAND WHEN *E. COLI* EQUALS UNITY (122)

Organism	Relative vulnerability
Bacillus subtilis, vegetative	1.68
Bacillus subtilis, spore	0.22
Bacillus diptheriae	1.16
Bacillus smegmatis	0.52
Bacillus prodigiosus	1.33
Streptococcus haemolyticus	0.97
Streptococcus viridans	0.93
Staphylococcus aureus	1.35
Staphylococcus albus	1.18
Pneumococcus I	1.94
Micrococcus catarrhalis	1.00
Bacteriophage	2.14
Sarcina lutea (computed)	0.85
Tubercle bacillus	0.84
Influenza virus	1.36

level, avoiding direct personnel exposure. Experts must be consulted for design criteria.

Incorporation of UV and fluorescent lighting fixtures will affect the reduction of microorganisms. According to one investigator, the incidence of measles was consistently lower in schools where UV fixtures were used and influenza infections were 2% compared to 19%. (123)

Low-pressure mercury vapor germicidal lamps provide the most effective source of shortwave UV energy. These lamps are made of special quartz glass that permits 70 to 90% of the short UV rays to pass, and they emit radiation that is predominantly at 2.534×10^{-7} m. This wavelength provides maximum germicidal effectiveness.

Sanitary Ventilation--

Sanitary ventilation, a combination of removing and killing bacteria, can be used with efficacy. For instance, in one experiment UV radiation increased the effect of ventilation by 9.7 times in absolute terms; i.e., with UV irradiation the effect of 12 air changes per hour was nearly equal to 116 air changes per hour without UV irradiation. (122)

Personal Worker Protection--

The personal protection of a worker may be provided by using respiratory protective devices and/or vaccinations.

Respiratory devices--Respiratory protective devices may be needed to prevent "lung burden" and possible long-range lung damage, but they should not be substituted for the controls mentioned above. It may be necessary to check the limitations of respiratory devices before using them. It is recommended by some experts that before issuing a protective device to a worker, he be examined physically and psychologically. (71)

Vaccination--Vaccinations should be used as a last line of defense. Their effectiveness depends on many variables such as selectivity of protection afforded, immune state of the individual at the moment of challenge, magnitude of the challenge, etc.

Vaccinations must be used in conjunction with the controls mentioned above. Good record-keeping practice is essential for continuous immunization through vaccination. (37)

Administrative controls--Personal hygiene is a fundamental aspect of public health engineering. Consumption of food and smoking in contaminated areas should be avoided and the use of showers to decontaminate skin may be imposed. Dry sweeping of floors should be avoided to keep dust containing microorganisms from becoming airborne. Periodic washing of floors with germicides is advantageous and the rotation of workers in work places may reduce individual lung burden.

The real key, however, to an effective administrative control program is concerted effort and a spirit of cooperation between labor and management.

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